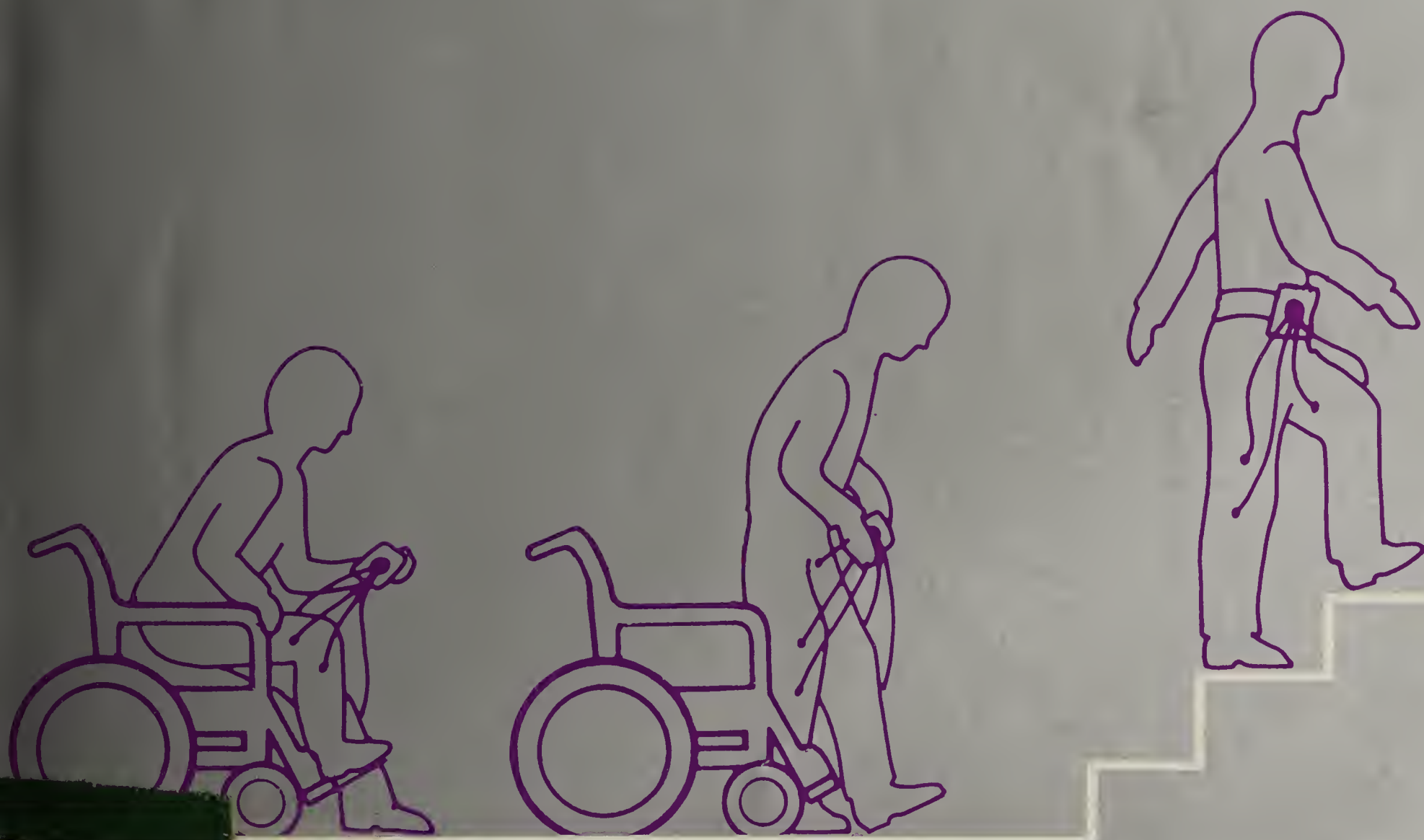
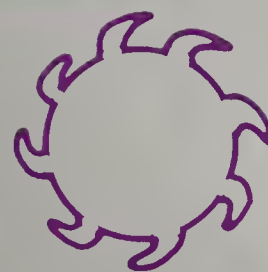


Rehabilitation R&D Progress Reports

1986



HV1786
R266
1986
Copy 1

ELECTRONIC PUBLISHING

This publication represents a pioneering cooperative effort among rehabilitation researchers, the Veterans Administration, and the Government Printing Office.

The entire text of this publication was typeset electronically using automated typesetting under the direction of the Graphics Systems Development Division, United States Government Printing Office in cooperation with the Technical Support Division, VA Office of Technology Transfer. The electronic typesetting system of formatting features presented in the text are original to this work and are expected to advance the state-of-the-art in the VA's publishing practice. In addition, a substantial number of VA and other researchers submitted progress reports in electronic form.

These innovations have allowed valuable information to reach veterans and others more quickly and at a lower cost than traditional methods.

Seldon P. Todd, Jr.
Director, Office of Technology Transfer

Development Team

Sidney K. Nichols, GPO, Graphics Systems Development Division,
Applications Section

Robert W. Armentrout, GPO, Customer Service

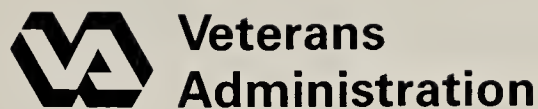
Robert G. Smallwood, Jr., VA, Office of Technology Transfer, Chief,
Technical Support Division

Holly Jellison, VA, Office of Technology Transfer, Managing Editor,
Journal of Rehabilitation Research and Development

Voneta Fifield, VA, Office of Technology Transfer, Electronic
Publishing Specialist

Lisa Jellison, VA, Office of Technology Transfer, Writer/Editor

H41786
R246
1986
copy 1.
65-87



Rehabilitation R&D Progress Reports

1986



**Rehabilitation R&D Progress Reports
is a publication of
The Veterans Administration,
Department of Medicine and Surgery**

Rehabilitation Research and Development Service
Office of Technology Transfer (153D)
Veterans Administration Medical Center
50 Irving Street, N.W.,
Washington, D.C. 20422

Guidelines for Submitting Progress Reports

We welcome contributions to the annual *Rehabilitation R&D Progress Reports*. It is our desire to provide a comprehensive review of research in progress and we want to ensure that significant work is included.

The reports are meant to facilitate access to sources of formal or informal information about completed or ongoing scientific research and engineering developments. Material presented will be published solely as statements of investigators on the progress of their work and not as short research papers.

Reports intended for the 1987 issue must be received at the Office of Technology Transfer (address below) no later than July 1, 1987. The text should follow the format of reports in the 1986 issue and contain a brief summary of the purpose, progress to date, and preliminary findings and/or results since the last report. If a project is not completed, a brief comment on future plans or goals is appropriate. The entire report should not exceed 600 words and should not contain any graphs, tables, diagrams, or photographs.

For completed projects, only a brief final summary should be supplied to *Rehabilitation R&D Progress Reports*. Detailed scientific findings should be submitted to the *Journal of Rehabilitation and Research Development* or other appropriate scientific journals for publication.

Please give bibliographic references for publications and/or patent information as applicable for all completed projects that were included in *Rehabilitation R&D Progress Reports* of 1983, 1984, 1985, and 1986.

Follow these publication requirements:

1) Submit typewritten reports on forms provided by the Office of Technology Transfer or on 8½ X 11 inch paper, letter-quality typed or printed, double-spaced, numbering the pages visibly.

2) We encourage you to send with your hard copy report the same material on a 5¼ inch floppy disk (non-returnable) IBM PC or PC-AT format. We are able to accept document files from the following word processor packages: Microsoft Word (preferred), WordStar, DisplayWrite (RTF format), MultiMate, Word Perfect, and any word processor that can generate a disk file containing only ASCII characters. Label your disk with computer type, word processor name, and file names included on the disk. You may also transmit progress reports to the Office of Technology Transfer by telephone modem. To make such arrangements, call the Technology Transfer Information Exchange System operator at (301) 962-1800.

3) Include investigator(s) name(s) with highest degree, position, organization, and location of the actual research activity (full address with zip code and telephone number of principal investigator).

4) Clearly indicate on the first page the source(s) of funding for the work described in the report with complete address and name of director so that a complimentary copy of the 1987 *Progress Reports* may be sent.

Address contributions to:

Editor
Rehabilitation R&D Progress Reports
Office of Technology Transfer (153D)
Veterans Administration Prosthetics R&D
Center
103 S. Gay Street
Baltimore, MD 21202

Progress reports and information on publications/patents relating to completed projects must be received by July 1, 1987 in order to be assured inclusion in the 1987 issue.



Veterans
Administration

Rehabilitation R&D Progress Reports 1986

Vol. 24 No. 1 of the *Journal of Rehabilitation Research and Development*

Margaret J. Giannini, M.D.

Director

Rehabilitation Research and Development Service,

Department of Medicine and Surgery, Veterans Administration

PUBLICATION STAFF

Seldon P. Todd, Jr., Editor

Tamara T. Sowell, Associate Editor

Holly M. Jellison, Managing Editor

Robert G. Smallwood, Jr., Chief, Technical Support Division

Voneta Fifield, Electronic Publishing Specialist

Margherite W. Williams, Senior Editor

Lisa Jellison, Writer/Editor*

David Gillard, Editorial Assistant

Eliane Janzegers, Editorial Assistant

A. Bennett Wilson, Jr., B.M.S.E., Technical Consultant

*Special acknowledgment is due Lisa Jellison, whose contributions as production coordinator of *Rehabilitation R&D Progress Reports 1986* exhibited an exemplary level of professionalism.

The opinions expressed in contributed material are those of the authors and those responsible for supplying the material, and are not necessarily those of the Veterans Administration.

Contents of *Rehabilitation R&D Progress Reports* are within the public domain, with the exception of material which was already under copyright when received and appears here with the permission of the copyright owner. Such copyrighted material is clearly identified as such on the page where it appears, and all such material in an issue is listed at or near this position in that issue.

Copyrighted material in this issue: NONE.

DISTRIBUTION/CIRCULATION POLICY

Rehabilitation R&D Progress Reports is distributed to recipients on the mailing list for the *Journal of Rehabilitation Research and Development*. The mailing list is intended to cover all professionals in the rehabilitation field who are either actively involved in research, contemplate such involvement or need to remain familiar with the direction and methods of current research and the clinical application of its results.

At present, the *Journal* and the progress report annual publication are distributed free of charge, both in the United States and in foreign countries. Additions will be made to the mailing list upon request.

Editor's note

The *Rehabilitation R&D Progress Reports* is an annual compilation of ongoing work in the field of rehabilitation research and engineering both in this country and abroad. Our goal has been to achieve increasingly comprehensive coverage in each annual edition. This edition represents a substantial increase in the number of progress reports included.

Now that *Rehabilitation R&D Progress Reports* is in its fourth year of publication, each issue not only presents a view of current work, but also allows readers to study the progress of selected research over a three or more year period. In this issue we have asked contributors to list publications and patents that have resulted from research reported in earlier issues. The inclusion of this information is intended to assist readers in obtaining the results of completed research. A major expansion of this coverage is planned for the 1987 edition of the *Progress Reports*.

In support of the Rehabilitation Research and Development Service's commitment to serve aging veterans, a section on geriatrics is now included in this publication.

The sponsor index lists participating agencies and organizations along with the research projects each has funded over the past year. Contributors are listed alphabetically with the page numbers of their reports in the final section of the book.

The deadline for submitting progress reports for the next issue is July 1, 1987. Guidelines for content and format are on page ii.

On the Cover:

An artist's conception of functional electrical stimulation (FES) in which paralyzed muscles are selectively stimulated by implanted electrodes to restore leg movements required for walking. Progress reports on this topic are featured in **Section IV, Spinal Cord Injury, I. Functional Electrical Stimulation**. Additional reports related to FES are found in other parts of the book as well. Cover design by Holly M. Jellison.

Contents

I. Amputations and Limb Prostheses

- 1 A. General**
- 1 Thermographic and Electromyographic Correlates of Stump and Phantom Limb Pain
- 1 Psychological Factors Influencing Chronic Phantom Limb Pain: Analysis of the Literature and a Survey of Locus of Control
- 2 Fluorometric Quantification of Low-Dose Fluorescein Delivery to Predict Amputation Healing
- 2 Development of Materials for Percutaneous Passage
- 3 Myoelectric Controller for Orthotic/Prosthetic Systems
- 4 B. Lower Limb**
- 4 1. General**
- 4 Computer-Aided Alignment of Lower Limb Prostheses and "Expert" Systems
- 5 Automated Fabrication of Lower Extremity Prosthetic Sockets
- 6 CAD/CAM of Lower Extremity Prostheses: The San Antonio System
- 7 Ultrasound as an Aid to Prosthetic Socket Design
- 7 Computerized Tomography as an Aid to Prosthetic Socket Design
- 8 The 3-D Digitizer as an Aid to Prosthetic Socket Design
- 8 Study of Alignment in Lower Limb Prostheses
- 9 The Effect on Gait Using Various Ankle-Foot Devices
- 10 Survey of Design Criteria for Prosthetic Knee and Ankle Joints
- 10 Fiberoptic Fluorometry as a Useful Adjunct in Determining Lower Extremity Amputation Level
- 11 Determining the Need or Level of Amputation by Assessing Nutritive Skin Blood Flow
- 12 Aerobic Training Improves Cardiovascular Fitness and Increases Efficiency of Walking in Lower Limb Amputees
- 12 Relation Between Cardiac Condition of Leg Amputees and the Success of Their Prosthetic Rehabilitation
- 13 Limb Viability: Vascular Reconstruction and Amputation Surgery
- 14 Use of Cutaneous Pressure Photoplethysmography in Managing Peripheral Vascular Occlusive Disease
- 14 Clinical and Laboratory Study of Amputation Surgery and Rehabilitation

I. Amputations and Limb Prostheses	16	B. Lower Limb
	16	2. Below-Knee
	16	Sockets with Flexible Brims
	16	Adjustable Below-Knee Socket
	17	ISNY Below-Knee Flexible Socket
	18	Analysis of Below-Knee Suspension Systems: Effect on Gait
	18	Computer-Aided Analysis of Below-Knee Socket Pressure
	19	Optimum Prosthetic Foot Characteristics for the Dysvascular Below-Knee Amputee
	21	B. Lower Limb
	21	3. Above-Knee
	21	Geriatric Prosthetics: Design and Development of an Improved Above-Knee Socket
	22	Rigid Knee Prosthesis
	23	Myoelectrically Controlled Above-Knee Prosthesis
	24	Transparent Flexible Sockets for Above-Knee Prostheses
	24	A Telemetric Data Acquisition and Processing System for Biofeedback Training and as a Diagnostic for Human Movement Training
	25	C. Upper Limb
	25	1. General
	25	Improvement of Body-Powered Upper Limb Prostheses
	26	Myoelectric Prosthetic System
	26	Extended-Limb Prostheses
	27	An Electric Artificial Limb for Children Without Limbs
	28	Design of Prehension Systems for Upper Limb Amputees
	28	Position-Servo Control of Upper Limb Powered Prostheses
	29	Cosmetic Covers for Upper Extremity Prostheses (Male/ Female)
	29	Prosthetic Terminal Device for Playing the Piano
	30	Quantification for the Functional Capability of Upper Extremity Amputees
	31	A Microprocessor-Controlled Prosthesis with Extended Physiological Proprioception
	32	Implementation of Extended Physiological Proprioception for Prosthesis Control
	32	C. Upper Limb
	32	2. Below-Elbow
	32	Below-Elbow Prosthetic System
	33	Acceptability of the "Contour" Terminal Device for Below- Elbow Amputees
	33	The VIENNA ROTATION ARM—a Below-Elbow Prosthesis

II. Orthotics

- 35 The Role of Pressure Distribution Measurement in Diabetic Foot Care
- 35 Biomechanics of Knee-Ankle-Foot Orthoses
- 36 Technical and Clinical Evaluation of Self-Fitting Modular Orthoses (SFMOs)
- 37 A Viscoelastic Knee Brace for ACL-Deficient Patients
- 38 Standing Frame Lift Mechanism
- 38 Design of External Joint Assemblies Using CAD-CAM Techniques
- 40 Orthotics
- 40 Lightweight Knee Joint for Child-Size Orthoses
- 40 Development of a Powered Orthosis for Lower Limbs
- 41 Molded Shoe
- 42 Bioengineering Research and Development at Instituto Mecánica Aplicada (IMA)

III. Total Joint Replacement and Other Orthopaedic Implants

- 43 **A. General**
- 43 The Effect of Notching of Simplex-P Bone Cement on the Fatigue Lives of Regular Versus Vacuum-Mixed Specimens
- 44 Bone Remodeling Around Ingrowth Joint Implants
- 44 Investigation of the Bone/Bone Cement/Implant Interface Formed by Total Joint Replacement
- 46 Mechanical Properties of Trabecular Bone Tissue
- 46 Expert Manufacturing System for Custom Prosthesis
- 47 Porous Polyethylene as a Reconstructive Material
- 47 Bone Remodelling Around Porous-Ingrowth Implant
- 48 Biomechanics of Bone Resorption/Regeneration at a Bone Implant Interface
- 49 Evaluation of Total Joint Implant Loosening Using X-Ray Photogrammetry
- 50 The Efficacy of Radiolucent Low Modulus Total Hip Surface Replacement
- 50 Implant Fixation by Postinsertion Pressurization of Polymethylmethacrylate
- 51 Development of Biologic Cement for Fixation of Skeletal Implants
- 52 Segmental Bone and Joint Replacement After Tumor Resection
- 52 Weight Distribution in the Foot Before and After Surgical and Orthotic Intervention for Hallux Rigidus
- 53 Orthopedic Implant Retrieval and Analysis
- 53 The Mechanical Properties of Porous-Coated Orthopaedic Alloy

III. Total Joint Replacement and Other Orthopaedic Implants	<p>55 B. Hip</p> <p>55 Quantitative Analysis of the Effect of Total Hip Arthroplasty on Stress and Strain in the Human Pelvis</p> <p>55 Design Analysis of Porous-Ingrowth Hip Replacement</p> <p>56 Skeletal Aging and Disease in Failure of Hip Surface Replacement</p> <p>58 Photoelastic Investigation of Hip Replacements</p> <p>58 A New Method of Hip Function Assessment</p> <p>58 Total Hip Biotelemetry</p> <p>59 C. Knee</p> <p>59 Investigation of a Simplified Internal Knee Prosthesis</p> <p>61 Stiffness and Porosity of Cancellous Bone from Total Knee Patients</p> <p>61 Synatomic Knee Clinical Investigation</p> <p>62 Design Concepts for a Porous-Ingrowth, Prosthetic Tibial Component</p> <p>63 D. Other</p> <p>63 Evaluation of Elbow Joint Function Post-Elbow Joint Arthroplasty</p> <p>64 Stress Analysis for the Normal and Prosthetic Shoulder</p> <p>65 Design of a Two-Component Finger Prosthesis</p>
IV. Spinal Cord Injury	<p>66 A. General</p> <p>66 The Use of EMG Biofeedback and Functional Electrical Stimulation in Spinal Cord Injury</p> <p>67 Microwave Myelography: A Feasibility Analysis</p> <p>67 Corticospinal Systems</p> <p>68 Role of Intrinsic Motoneuron Properties in Abnormal Rate Regulation After Spinal Injury</p> <p>69 An Implantable Sensor for Two-Degree-of-Freedom Position Transduction</p> <p>69 Trial of a 5-Lipoxygenase Inhibitor in Experimental Spinal Cord Injury</p> <p>69 Circulation and Metabolism in the Decentralized Spinal Cord</p> <p>70 Retrospective Analysis of the National Spinal Cord Injury Care System Database</p> <p>71 Devices to Assist Transport, Diagnosis, and Treatment of Acute Spinal Injury Patients</p> <p>72 Documenting and Utilizing Programs that Provide Community Adjustment and Independent Living Services for Persons with Spinal Cord Injury</p> <p>73 Assessment, Development, and Clinical Applications of Strategies to Coordinate Services for Spinal Cord Injured Clients After Discharge</p> <p>74 Longitudinal Assessment of Physical Therapy Factors in the Rehabilitation Process that Affect the Quality of Life of Spinal Cord Injured Persons</p>

- 75 Longitudinal Assessment of the Utilization of Upper
Extremity Assistive Devices Prescribed for the Spinal
Cord Injured Quadriplegic
- 76 Outcome Studies Pertinent to the National Model Spinal
Cord Injury System
- 77 Development of Reconditioning Exercise Program for
Patients with Paraplegia
- 77 Vocational Evaluation for Quadriplegics with a High School
Education or Less
- 78 A Center for Acute Spinal Cord Injury: Epidemiology and
Economic Costs of Spinal Cord Trauma
- 79 **B. Medical Treatment**
- 79 A Collision Block Technique for Micturition Assist:
Preclinical Studies
- 79 A Laboratory Test to Predict and Monitor Bone and Skin-
Related Complications in Spinal Cord Injured Patients
- 80 Skin Temperature in Spinal Cord Injury Related to Skin
Breakdown
- 80 Prospective Randomized Clinical Trial of Thyrotropin-
Releasing Hormone as a Therapy for Spinal Cord Injury
- 81 Respiratory Dysfunction in Spinal Cord Injury: Control of
Ventilation
- 81 Urinary Bladder Ganglion Reorganization Following Lesions
- 82 Pharmacokinetics of Drugs in Spinal Cord Injured Persons
- 82 Actions and Metabolism of TRH in the Spinal Cord
- 83 Factors Affecting Sodium and Water Homeostasis in SCI
- 83 Circulorespiratory Effects of Dynamic Arm Exercise in
Spinal Cord Injured, Quadriplegic Males
- 84 Neural Mechanisms Underlying Bladder Dysfunction After
Spinal Trauma
- 84 Differences Between Chest Heat Patterns Shown by
Complete and Incomplete Spinal Cord Injured Veterans
- 85 The Spasticity of Spinal Cord Injury
- 85 Effect of Intermittent Catheterization on Renal Stone
Formation in Spinal Cord Injury Patients
- 86 Natural History and Clinical Course of Urinary Tract
Complications in Patients With Spinal Cord Dysfunction
- 87 A Bladder Sensor for Urinary Incontinence
- 88 Clinical Evaluation of an External Device for Urinary Care
in Incontinent Women
- 89 Incidence, Characteristics, and Clinical Significance of
Anemia in Patients with Spinal Cord Dysfunction
- 89 Effects of Nutritional Intervention During the Acute Phase
of Spinal Cord Injury
- 90 Incidence and Clinical Significance of Impaired Brain
Function in Spinal Cord Injury

IV. Spinal Cord Injury

- 91 Pain Secondary to Gunshot Wound During the Initial Rehabilitation Process in Spinal Cord Injury Patients
- 92 Didronel in the Prevention of Heterotopic Ossification Following Spinal Cord Injury: Determination of an Optimal Treatment Schedule
- 93 The Relationship of Nutritional Status and the Occurrence of Secondary Complications in Spinal Cord Injury Patients
- 93 Collagen Dysfunction in Quadriplegia
- 94 Effects of Spinal Cord Injury on Drug Metabolism
- 95 Mechanism of Active Expiration in Tetraplegic Subjects
- 95 Evaluation and Rehabilitation of Reproductive Function in Paraplegia
- 96 A Feasibility Study on Detection of Impending Pressure Sores Using Ultrasound
- 97 Skin Deformation and Blood Flow Under External Loading
- 98 Biochemical Analysis of Sweat as an Indicator of Tissue Viability
- 99 **C. Spinal Cord Regeneration**
- 99 An *In Vivo* Model to Assess the Neurotrophic Function of Mammalian CNS Glia
- 100 Plasticity in the Injured and Aging Mammalian Spinal Cord
- 100 A Study of Phosphoprotein in a Regenerating CNS Tract
- 101 Spinal Cord Regeneration of Descending Locomotor Command Systems in a Lower Vertebrate, the Lamprey
- 101 Fetal Spinal Cord Transplantation into the Chronically Injured Rat Spinal Cord
- 102 Study to Determine if Localized Extracellular Proteolysis Is a Requirement for Successful Regeneration of Nervous Tissue
- 102 Axon Regeneration in the Mammalian Spinal Cord in Response to Surgical Denervation and Nerve Growth Factor
- 103 Axonal Regeneration in the Adult Spinal Cord
- 104 Recovery of Function and Anatomical Repair After Spinal Cord Transections in Newborn and Adult Rats
- 105 Development and Regeneration of Afferent Motoneuron Contacts in Rat Embryos
- 106 Evaluation of a Novel Spinal Cord Injury Model
- 106 Spinal Cord Explants Cultured on Carbon Filaments and Stimulated with Direct Current
- 107 Influence of Continuous Electrical Stimulation On the Spinal Cord Motor Neurons
- 108 **D. Independent Living for the Severely Disabled**
- 108 Parameters of Independent Living Programs: A Longitudinal Study
- 108 Independent Living in Rural Areas: A Longitudinal Study

- 109 An Operational Definition of Independence
- 110 **E. Communication Methods and Systems for the Severely Disabled**
- 110 Capuchin Monkeys as Aides for the Severely Disabled
- 110 An Optimal, Inexpensive Text Entry System for the Orthopaedically and Neurologically Disabled
- 111 Software Development of Alternate Inputs to IBM PC
- 111 PACA—Portable Anticipatory Communication Aid
- 112 CompuTalk
- 113 Electrically Controlled Talking Tracheostomy Systems
- 114 A Single Switch Keyboard Emulator for the IBM PC
- 115 Development of a Unified Quantitative Model for Augmentative Communication Systems
- 115 Comm-Aid
- 116 Application of Technology to Enhance the Employability of Severely Communicatively Impaired Individuals
- 117 Neuromuscular Assessment for Assistive Communication Device
- 117 Investigations on a Communication System for the Severely Handicapped
- 118 **F. Environmental Control Systems for the Severely Disabled**
- 118 UHCI: Ultrasonic Head Control Interface
- 119 Interactive Motion and Graphic Environmental Simulation
- 120 Voice-Actuated Control System
- 121 Design of Showers and Bathing Fixtures for Disabled and Elderly Veterans
- 122 Development of a Robotic Arm for Use by the Physically Disabled
- 123 Investigation of the Utilization of a Robotic Arm by Disabled Persons in the Workplace
- 124 Machine Vision
- 125 Blinkwriter
- 126 VME—CAD
- 127 Voice Control for Disabled Children
- 127 Overhead Rail Adaptation
- 128 Development and Evaluation of an Advanced Manipulation Aid for the Severely Disabled
- 129 Design of a Six-Axis Joystick for a Robotic Manipulation Aid
- 130 Design of an Omnidirectional Mobile Robot as a Manipulation Aid for the Severely Disabled
- 131 Computer Configuration of the Advanced Robotic Aid
- 132 Force/Proximity Integrated Sensory Perception for the Robotic Aid System
- 133 Architecture of the User-Interface Software of the Robot Control Workstation

IV. Spinal Cord Injury	134	Design and Development of an Interactive Workstation for a Robotic Manipulation Aid
	135	Safety Features Implemented on a PUMA 560 Robot Used in an Applications Setting
	136	Laboratory Robotic Arm Testing Environment
	137	Development of a Training and Reference Manual for a Robotic Manipulation Aid
	138	Evaluation of Robotic Aids for the Severely Physically Disabled
	139	Eating and Hygiene Tasks for the Robotic Aid
	140	The Role of Choreographic Exploration in the Design of the Robotic Aid
	141	Aesthetic Implications of Robotic Movement: A Case Study
	142	Development of Environmental Control Units for Disabled Veterans
	142	Analytic Techniques for Automated Grasp
	143	The Application of Continuum Methods to Path Planning
	143	Computer Methods in Manipulator Kinematics, Dynamics, and Control: A Comparative Study
	144	G. Wheelchairs, Including Seating and Controls
	144	University of Virginia Rehabilitation Engineering Center
	145	Development of a Linear Synchronous Motor for Wheelchair Use
	146	Developing Safety Standards for Wheelchair Occupants in Vehicles
	147	Optimal Biomechanical Design/Development of Arm-Powered Mobility Devices
	147	Powered Wheelchair Performance
	148	Wheelchair Controls
	148	Three-Wheeled Vehicle
	149	Steiner Tractor Modification
	149	Seat Cushions for the Paralyzed
	150	Remote Monitoring of Pressure Relief Activity and Sitting Asymmetry in the Wheelchair User
	151	Wheelchair Seating Effectiveness
	151	CUSHFIT: An Expert System for Wheelchair Cushion Prescription
	152	A Computer Interface for the TIPE Seating Pressure Evaluator
	153	Seating Systems for Body Support and Prevention of Tissue Trauma
	154	Seating Systems Analysis
	155	Wheelchair Control and Robot Arm/Worktable Systems for High Spinal Cord Injured Persons
	156	Wheelchairs: On-Line Measurement and Storage of the Load During a Field Trial
	157	A New Wheelchair Bumper

- 157 Bicycle-Type Brakes for Wheelchairs
- 157 Bioengineering Research and Development at IMA:
Rehabilitation Engineering. Economic Cushion Seat of
Variable Configuration for Cerebral Palsy Children
- 158 Mini Litters: A Specialized Mobility Construction for Spinal
Cord Injured Patients with Bilateral Lower Limb
Amputations and Diminished Seating Capacity
- 160 **H. Personal Licensed Vehicles**
- 160 Unistik Vehicle Controller: Reliability, Applications, and
Secondary Controls
- 161 **I. Functional Electrical Stimulation**
- 161 **1. General**
- 161 EMG as Force-Feedback in Closed-Loop Functional Electrical
Stimulation
- 162 Implantable Systems for Stimulation of Skeletal Muscle
- 163 Recruitment Properties of Nerve Cuff and Epimysial
Electrodes
- 163 Ljubljana Rehabilitation Engineering Center—Core Area:
Functional Electrical Stimulation
- 164 Implantable Multichannel Implant Systems
- 166 Neuroaugmentive Procedures for Modification of Abnormal
Motor Control in Patients with Spinal Cord Injury
- 166 Evaluation of the Effectiveness of Electrical Stimulation of
the Leg Muscle in Cerebral-Palsied Patients
- 167 Adaptive Neuromuscular Stimulator
- 167 Fitness Improvements and Physiological Responses to FES
Exercise
- 169 **2. Upper Limb Applications**
- 169 Sensory Augmentation for FES Upper Extremity Prostheses
- 170 Implantable Sensor for Two-Degree-of-Freedom Position
Transduction
- 170 Functional Neuromuscular Systems for Upper Extremity
Control
- 171 Functional Electrical Stimulation in Upper Extremity
Muscles of Spinal Cord Injured Patients
- 172 **3. Lower Limb Applications**
- 172 Walking Restored in Paralyzed Man Using Electronic
Orthotics
- 172 Electrical Stimulation of Paralyzed Muscle After Spinal
Injury
- 173 Sensory Prosthetic Feedback and Application to the FES—
Orthosis Systems
- 174 Computer Models for Designing Functional Electrical
Stimulation Systems for Paraplegic Standing and Walking
- 174 Open-Loop Control of the Paralyzed Human Knee

IV. Spinal Cord Injury	175	Triggers for Control of Implantable Gait-Assist Systems
	176	Computer-Controlled 22-Channel Stimulator for Limb Movement
	177	Lower Limb Function with FES
	177	A Computer Model for Control of Paraplegic Posture
	178	Functional Electrical Stimulation in Dropped-Foot Conditions
	179	Restoration of Locomotion in Paraplegics Using Functional Electrical Stimulation
	180	4. Other
	180	Fitness Improvements and Physiological Responses to FES Exercise
	180	Predictive Factors for Restrengthening Paralyzed Muscle by Electrical Stimulation
	181	Electrical Stimulation of Osteogenesis Using Selected Techniques
	182	Value of Electrical Stimulation on Fertility in Male Patients with Spinal Cord Dysfunction
	182	Cardiovascular Circulatory Dynamics in Quadriplegics With and Without Functional Electrical Exercise (Active Physical Therapy)
	183	Electrical Muscle Stimulation for the Prevention of Pressure Sores: 1) Pressure Studies
	184	Electrical Muscle Stimulation for the Prevention of Pressure Sores: 2) Ultrasonic Shape Imaging Studies
	185	Rehabilitation of Fast and Slow Skeletal Muscle
	185	Treatment of Spastic and Paretic Muscles in CP Children
V. Functional Assessment	186	Ambulatory Physiological Monitoring Device
	187	Long-Term Ambulatory Physiological Surveillance Equipment (LAPSE)
	187	Predictive Assessment in Prescription of Functional Aids for the Motor Disabled
	188	Improved Methods of Quantification of Function/Performance
	189	Development of a Computer-Automated System for Functional Assessment
	190	Clinical Evaluation and Application of a Computer-Automated System for Functional Assessment—Part 1
	191	Clinical Evaluation and Application of a Computer-Automated System for Functional Assessment—Part 2
	191	Quantification of Mobility Performance for Functional Assessment, Diagnosis, and Therapy of Neuromuscular, Skeletal, and Synovial Joint Dysfunctions
	193	Upper Extremity Control Utilizing Functional Neuromuscular Stimulation (FNS)

V. Functional Assessment	194	Nerve-Bundle Conduction Velocity Distributions: Clinical and Research Applications
	195	Psychiatric Symptoms and the Functional Capacity to Work
	196	Development and Evaluation of Dynamic Pedobarograph (DPBG) System for Clinical Use
VI. Biomechanics	197	A. Joint Studies
	197	1. General
	197	Biomechanical Studies of Bones and Joints
	197	The Antagonist Muscle and Its Role in Maintaining Joint Stability
	198	2. Lower Limb
	198	Pathokinesiology of Anterior-Cruciate-Ligament Deficiency
	198	Development of Diagnostic and Therapeutic Procedure for Anterior-Cruciate-Ligament-Deficient Knees
	199	Computer Simulation of Knee Joint Mechanics
	200	Comprehensive, Quantitative, Predictive Model of the Human Knee Joint
	201	B. Spine
	201	Trunk Analysis System
	202	Mechanisms of Cervical Spine Injuries
	203	C. Human Locomotion and Gait Training
	203	Gait Analysis By Use of an Instrumented Treadmill
	203	The Muscular Biomechanics of Human Posture
	204	Effect of Shock-Absorbing Materials on Heel-Strike Forces
	205	Foot Interface Pressure Study
	206	Swing-Through Crutch Ambulation by Persons with Paraplegia
	207	Weight Transfer Using Biofeedback
	207	Gait, Balance and Symmetry in Hemiplegia: An Analysis With and Without Biofeedback Retraining
	208	A Modular Gait Analysis System
	209	Human Movement Monitoring System to Study Posture, Walking and Jumping
	210	D. Upper Limb Applications
	210	Analysis of Hand Performance Patterns in Able-Bodied and Cerebral-Palsied Subjects
	211	E. Other
	211	Mathematical Models for Bone Inelasticity and Bone Damage
	212	Bone Fatigue and Creep Damage
	213	Mechanical Stress Influences on Cartilage Degeneration and Ossification
	214	The Influence of Exercise on the Regulation of Bone Density

VI. Biomechanics	215	Prediction of Cancellous Bone Apparent Density and Orientation
	216	Development of a Musculoskeletal Model of the Human Lower Extremity
	217	A Musculotendon Actuator Model for Use in Computer Studies of Neural Control and Biomechanics of Movement
	218	Neuromuscular Control and Biomechanics of Pedaling and Jumping
	219	Intermuscular Coordination of Mammalian Movement
	219	The "White Knuckle" Technique for Studying Skin Behavior Under Load
	220	Bone <i>In Vivo</i> and <i>In Vitro</i> Stress and Strain Patterns: Influence of Age and Activity
	221	A Model for Postural Sway
	221	Measurements of Postural Sway
	222	Visuomotor Effects on Postural Sway
	222	Gross Motor Behavior in Late Childhood and Early Adolescent Children with Down's Syndrome
	223	Visual Control of Step Length During Running
	223	Modulation of Tonic and Phasic Reflexes with the Skin
	224	Electromagnetic Modulation of Cellular Interaction in Natural and Foreign Environments in Bone
	226	Enhancement of Union of Segmental Defect Fractures
VII. Wound and Fracture Healing	228	Electrical Stimulation for Augmentation of Wound Healing
	228	Development of a Mathematical Model of Fracture Healing in Long Bones
	229	Bioelectricity in Fracture Healing
	230	Stimulation of Repair of Cortical Bone Transplants by Implantation of Piezoelectric Materials: A Development Study
	231	Stress Analysis of Internal Fracture Fixation of Long Bones
	232	Quantifying Fracture Healing by Impulse Transfer Functions
	233	Altered Collagen and Wound Metabolism in Non-Healing Diabetic Ulcers
	234	Morphological and Clinical Studies of Microwounds in Ischemic Human Tissue
	234	Transcutaneous Oxygen Tension as Predictor of Wound Healing
	235	Enhancement of Ulcerated Tissue Healing by Electrical Stimulation
	236	Acceleration of Fracture Healing Electrical Fields
	236	Biomechanics of Metastatic Defects in Bone
	237	Management of Burn Injuries
	237	Quantitative Evaluation of Nerve Repair

VII. Wound and Fracture Healing	<p>239 Nerve Coupler—Sutureless Peripheral Nerve Repair at the Fascicular Level</p> <p>240 Evaluation of Tubular Internal Fixation Plate for Fracture Management</p> <p>241 Biomechanical Considerations of Metal and Composite Materials for Bone Fracture Fixation Plates</p>
VIII. Properties of Muscle	<p>242 A. General</p> <p>242 Cross-Talk Between Myoelectric Signals of Adjacent Muscles</p> <p>242 Topical Anesthesia and Muscle Hypertonicity</p> <p>243 Surface Electrode Design</p> <p>243 Multi-Channel Surface Electrode Array</p> <p>244 B. Muscle Contraction</p> <p>244 The Myoelectric Signal Decomposition Technique</p> <p>244 Control of Antagonist Muscles</p> <p>245 Motor Control in Movement Disorders</p> <p>245 Synchronization of Motor Unit Discharges</p> <p>246 Force Output of Muscles During Voluntary Isometric Contraction</p> <p>247 Sensorimotor Interaction in Motor Unit Control</p> <p>247 Automatic Decomposition of the Electromyogram</p> <p>248 Quantitative Analysis of the Surface Electromyogram</p> <p>249 A Smart Trigger for Real-Time Neuroelectric Spike Classification</p> <p>250 The EMG-Force Relationships of Skeletal Muscles Depends on Their Firing Rate and Recruitment Control Strategies</p> <p>250 C. Muscle Fatigue</p> <p>250 Muscle Fatigue and the Myoelectric Signal</p> <p>251 Muscle Fatigue and Back Pain</p> <p>252 Fatigue Properties of Motor Units During Voluntary and Electrically Induced Contractions</p> <p>252 Muscle Fatigue Monitor</p>
IX. Ligaments and Tendons	<p>254 Muscle Fatigue and Back Pain</p> <p>254 Structural and Functional Properties of Normal and Repaired Ligaments</p> <p>255 Tensile Properties of the Medial Collateral Ligament as a Function of Age</p> <p>255 Effects of Postmortem Storage by Freezing on Ligament Tensile Behavior</p> <p>256 Structural and Mechanical Behaviors of Tendons and Ligaments</p>

X. Arthritis

- 257 The Use of Biofeedback and Cognitive Behavioral
Psychotherapy in the Treatment of Severe Rheumatoid
Arthritis Patients: A Controlled Evaluation
- 258 Arthritis Rehabilitation Unit
- 259 Impact of Arthritis Self-Care for Rural Persons
- 259 Multipurpose Arthritis Center: Stanford University
- 260 Multipurpose Arthritis Center: Boston University
- 261 Northeast Ohio Arthritis Center Support: Legal Aspects of
Chronic Illness—A Study of Arthritis Patients
- 261 Multipurpose Arthritis Center: Community Component—
Coping Responses to Rheumatoid Arthritis; Social Security
Disability Study; Role Performance Limitations in Women
With RA
- 262 Multipurpose Arthritis Center: Pain Management in
Arthritis; Physical Conditioning Exercise Programs for the
Arthritis Patient; Motor Skill Learning; Mini-Sabbatical
for Physical and Occupational Therapists
- 262 Multipurpose Arthritis Center: Community Component—
Studies Using a Panel of Rheumatoid Arthritis Patients;
Secondary Data Studies; Education Component—Arthritis
In-Service Program for Home Health Agencies
- 263 A National Arthritis Data Source (ARAMIS)
- 264 Epidemiology Program Project: Rheumatoid Arthritis—
Course and Outcome
- 264 Multipurpose Arthritis Center: Problem-Oriented
Educational Program for Arthritis Using Aerobic-Type
Exercise
- 265 Multipurpose Arthritis Center: Education—Arthritis Patient
Education Model; Medical Allied Health Professions
Integrated Curriculum in Arthritis; Arthritis
Rehabilitation Training Program for Industrial Managers;
Disability Determination of Arthritis
- 266 Robert B. Brigham Multipurpose Arthritis Center: Feasibility
Study—Evaluation of Total Knee Replacement by Gait
Analysis; Community Component—Social Security
Disability Study
- 266 Study of Behavioral Aspects of Rheumatoid Arthritis
- 267 Energy Conservation and Joint Protection in Rheumatoid
Arthritis
- 268 Ferrographic and Biochemical Analysis of Wear Particles in
Human Joints

XI. Low Back Pain

- 269 Low Back Pain Assessment, Prevention, and Rehabilitation
- 269 Biomechanics: Effects of Low Back Pain Treatment
Modalities on Lumbar Facet Loading

XI. Low Back Pain	<p>270 Myoelectrical Assessment of Human Lumbar Muscle Function</p> <p>271 Surgery for Severe Spinal Deformity and Back Pain</p> <p>271 Personality Characteristics and Their Effect on Post-Surgical Adjustment</p> <p>272 Chronic Pain Mechanisms and Manifestations: Psychological Treatment for Chronic Back Pain</p> <p>273 ND: YAG Laser Effect on Spinal Discs and Nerves</p> <p>273 A Comparative Analysis of Electrical Stimulation and Exercise to Improve Trunk Strength and Endurance in the Adult Female</p>
XII. Muscular Dystrophy	<p>275 A Study of the Mechanism of Spinal Collapse in Duchenne Muscular Dystrophy</p> <p>275 Forearm Levitation</p> <p>276 The Role of Spinal and Abdominal Muscles as Etiological Factors in Scoliosis in Neuromuscular Disorders</p> <p>277 A Random Crossover Trial of Respiratory Muscle Endurance Training in Duchenne Muscular Dystrophy</p>
XIII. Sensory Aids	<p>278 A. Blindness and Low Vision</p> <p>278 1. General</p> <p>278 An Auditory Data-Flow Indicator for the Blind</p> <p>278 Auditory Breakout Box</p> <p>279 Pediatric Vision Screening</p> <p>280 Assessment of the Spatial and Temporal Characteristics of Vision as a Function of Age</p> <p>281 The Effects of Preview Distance on Blind Mobility</p> <p>281 The Elderly Blind Client: Factors Associated with Employment Outcome</p> <p>282 Factors Influencing Employment Outcomes of Legally Blind Rehabilitation Clients Who Have Hearing Impairments</p> <p>283 Prevocational Skill Acquisition of Multiply Handicapped Blind Youth Using Adapted Electromechanical Assessment Devices</p> <p>283 Low Vision Performance as a Function of Environmental and Stimulus Characteristics</p> <p>284 Electromechanical Vocational Assessment Technology for the Evaluation of Industrial Work Abilities of Blind and Visually Impaired Persons</p> <p>285 Modification and Adaptation of the Vocational Education Readiness Test for Blind/Severely Visually Impaired Individuals</p> <p>286 Development and Validation of a Work Environment Visual Demands (WEVD) Protocol</p> <p>286 The Effects of Sensory Aids on the Employability and Career Development of Visually Impaired Persons</p>

XIII. Sensory Aids

- 287 Perceptions of Teachers, Rehabilitation Counselors, and
Rehabilitation Administrators of the Career Development
Needs of Blind and Visually Impaired Students and
Adults
- 288 Career Development Needs of Blind and Visually Impaired
Students and Adults
- 288 Predicting Work Status Outcomes of Blind/Severely Visually
Impaired Clients of Rehabilitation Agencies
- 289 Blind Clients Closed as Homemakers: Employment Outcome
Antecedents
- 290 Training Opportunities Profile for Visually Impaired
Persons: (TOP-VIP)
- 291 The Unsuccessfully Closed Blind Client: Employment
Outcome Antecedents
- 292 Research into the Development of a Nonisomorphic
Codification System for Electrocutaneous Sight
Substitution
- 293 Microcomputer Magnification for Low-Vision Users
- 294 Sensorimotor Aspects of Visual Rehabilitation Using Head-
Mounted Magnification Devices
- 295 Trisensor Rearing with Infant Macaques
- 295 Sensory Aids and Spatial Training of Blind Children
- 296 Rabbit ERG Responses to White-Noise Modulated Stimuli
- 297 The Correlation of Retinal Sources with the
Electroretinogram
- 297 Local Authority Social Rehabilitation Services to Visually
Handicapped People
- 298 Development of a Visual Evaluation and Training Book: The
Vet Book
- 299 QUO VADIS: Voice-Output Questionnaire Administrator
- 300 The Effectiveness of a Blind Rehabilitation Program
- 301 Predicting the Visual Abilities of Partially Sighted Persons
- 302 Computer Vision for the Blind
- 302 Pilot Studies in the Area of Sensory Substitution
- 303 **2. Mobility Aids**
- 303 Measuring the Mobility of Blind Travelers
- 304 Clinical Application Study of Training Techniques and
Devices for the Blind
- 305 SONA-ECS
- 305 SONA-Sonic Orientation and Navigational Aid
- 306 **3. Reading Aids**
- 306 Tactile Graphic Braille Display
- 307 Establishing Design/Operational Features for Portable Blind
Reading Aids
- 308 Facilitating the Use of Tape Recorded Text by Students with
a Visual Handicap

- 308 Tactile Paper for Visually Handicapped
- 309 Enhancing the Reading Skills of Low Vision Individuals with Macular Loss
- 310 Human Factors Considerations in the Design of Large Print Visual Display Units
- 311 **B. Deafness and Hearing Impairment**
- 311 Development of a Digital Hearing Aid and Fitting Procedure
- 313 Using a Psychophysical Model to Design Hearing Aids for Sensorineural Hearing Loss
- 314 Electroacoustic and Behavioral Studies of the Effect of Ear Impedance on Hearing Aid Performance
- 315 Studies in Acoustic Feedback in Hearing Aids
- 315 The Laura Cochlear Implant
- 316 Development of a Cochlear Prosthesis
- 316 Matching Speech to Residual Auditory Function
- 317 Hearing Aid Characteristic Selection
- 318 Rehabilitation Strategies for the Hearing Impaired: A Digitally Programmable Master Aid
- 318 High-Frequency Acoustics in the External Human Ear (Phase I)
- 319 Multimicrophone Monaural Aids for the Hearing Impaired
- 319 Processor-Controlled Hearing Aid
- 320 Direct Measurement of Loudness Recruitment in Hearing-Impaired Veterans
- 321 Changes in Frequency Organization of the Cochlea During Aging
- 322 Clinical Trials with the Cochlear Implant Prosthesis: Speech and Voice Characteristics, Part I
- 322 Clinical Trials with the Cochlear Implant Prosthesis: Speech and Voice Characteristics, Part II
- 323 Implementation of Digital Measurement of Aural Acoustic Immittance
- 324 A Microprocessor and Signal Processor-Based Speech Training System for the Hearing Impaired
- 325 An Experienced User of Tactile Information as a Supplement to Lipreading: An Evaluative Study
- 325 The Effects of Cochlear Implantation on Speech Production
- 325 A Single-Transducer Vibrotactile Aid to Lipreading
- 326 Development of Materials for Computer-Assisted Instruction in Lipreading
- 327 Robotic Finger-Spelling Hand
- 327 **C. Speech Impairment**
- 327 Prescription Guide for Nonvocal Communication Devices
- 328 DEXTER: A Mechanical Finger-Spelling Hand for the Deaf-Blind

XIII. Sensory Aids

- 330 A Study of Speech Intelligibility Over a Public Address System
- 330 Measurement and Prediction of Benefit from Amplification
- 331 The Application of Microcomputers for the Treatment of Aphasic Adults
- 332 Drawing: Its Use as a Communicative Aid with Aphasic and Normal Adults
- 333 Maxillofacial Prosthetic Management of Neurogenic Tongue Dysfunction
- 333 Efficacy of Remote Treatment of Aphasia by TEL-Communicology
- 334 Computer-Aided Visual Communication for Severely Impaired Aphasics
- 336 Effects of Real-Time Biofeedback on Dysarthric Speech
- 336 Experimental Analysis of Acquisition and Generalization of Syntax

XIV. Head Trauma and Stroke

- 338 Efficacy of Multiple Input Phoneme Therapy in the Treatment of Severe Expressive Aphasia
- 338 An Evaluation of a Microcomputer-Based Cognitive Rehabilitation Program for the Severely Head-Injured
- 339 Establishment of a Central Nervous System Trauma Center
- 339 Establishment of a Central Nervous System Trauma Center
- 340 Aphasia Rehabilitation Program
- 340 Computer Acceptance of Maladaptive and Adaptive Aphasic Behaviors
- 341 The Microcomputer as a Cognition Orthosis
- 341 COGORTH: Cognition Orthosis Programming Language
- 342 Pharmacological Therapies in Central Nervous System Injury
- 343 Comparing Rat Brain Pathways from Normal and Transplanted Motor Cortex
- 344 Socio-Cultural Mechanisms of Rehabilitation in Old Age
- 344 Remediation of Left-Sided Neglect and Interpersonal Communication Following Hemispheric Strokes
- 345 Precursors of Stroke Incidence and Prognosis
- 346 Recovery from Aphasia in Stroke
- 346 Rehabilitative Software for Head Trauma Victims
- 347 Treatment of Affective Deficits in Stroke Rehabilitation
- 347 Community Study: Stroke Rehabilitation Using Volunteer Help
- 348 Community Model: Rehabilitation of Older Adults with Brain Injuries
- 348 Efficacy of Computer-Assisted Rehabilitation
- 349 The Impact of NMR on the Management of Brain Lesions
- 349 Evaluation of Family Stroke Education

XIV. Head Trauma and Stroke

- 350 Microwave Hyperthermia
- 351 A Prosthesis for Writing in Aphasia
- 353 Device Evaluation for Cognitively and Motor-Impaired People

XV. Geriatrics

- 354 Memory Remediation in Older Adults: A Computerized Interactive System
- 354 Nutrition and Health in the Aging Veteran Population
- 355 Evaluation of Independent Living Services for the Chronically Ill Elderly
- 356 Adjustment and Rehabilitation of Chronic Illness Among Older Americans
- 357 The Social and Medical Effects of Amputation on Elderly Veterans
- 357 Discharged Elderly Patients from the Memphis VA Medical Center Nursing Home Care Unit (NHCU): A Followup Study
- 358 Impact of a Geriatric Assessment and Rehabilitation Unit on Subsequent Health Care Expenditures
- 358 Low Vision Rehabilitation and Age-Related Maculopathy Syndrome
- 359 Bicycle Ergometer With Computer-Controlled Resistance and Video Display
- 359 Geriatric Dentistry Academic Award: Tufts University
- 360 Geriatric Medicine Academic Award: University of Chicago
- 360 Geriatric Medicine Academic Award: University of North Carolina/Chapel Hill
- 361 Geriatric Medicine Academic Award - NIA: New York Medical College
- 362 NIA Academic Award: University of North Carolina/Chapel Hill
- 362 Sociocultural Mechanisms of Rehabilitation in Old Age
- 362 Does Improvement in Mortality Mean Better Health?
- 363 Morbidity Risk Assessment in the Elderly
- 363 The Lives and Needs of Aging Mentally Retarded Persons
- 364 Effects of Aging Upon Communication: Prevalence of Hearing Loss
- 364 Perceptual Retention and Age
- 365 Learned Modification of Visceral Function in Man
- 365 Audiologic Findings in Aging Down's Syndrome Patients
- 365 Modeling Length of Stay for the Hospitalized Elderly
- 366 A Geriatric Record and Multidisciplinary Planning System
- 367 Iatrogenic Disease in Hospitalized Elderly Veterans
- 368 Computer-Based Expert System for Geriatric Psychiatry
- 369 Falls in the Elderly: A Randomized Study of Intervention and Impacts

XVI. Miscellaneous

- 371 Age-Related Changes in Sensorimotor Performance
- 371 Chest Wall Stiffness in Patients with Chronic Respiratory Muscle Weakness
- 372 Noninvasive Quantitation of Venous Reflux
- 372 The Definition of "Peer": Consumer Perspectives and Significance in the Delivery of Counseling Services
- 373 Predicting the Success of Lumbar Sympathectomy in Patients with Severely Ischemic Foot
- 374 A Short Awareness Course on Microcomputers in Rehabilitation and Special Education
- 374 Cardiac Rehabilitation: Preliminary Results and Treatment Efficacy
- 375 Reliability and Validity of CT and NMR
- 376 Skin Blood Flow by Helium Flux Effect of Skin Temperature
- 376 Comparison of Helium Flux and Laser Doppler Skin Blood Flow Measurements: Effect of Skin Temperature
- 377 Comparison of Helium Flux and Xenon Washout of Skin Blood Flow Measurements in Man
- 378 Evaluation of Cutaneous Blood Flow in Dysvascular Patients and Normals: Laser Doppler and Fluorometry
- 378 Return to Work After Cardiac Rehabilitation
- 379 New Technique for Dynamic Exercise Echocardiography
- 379 Data Collecting, Analysis, and Reporting Via Computer in Cardiac Rehabilitation Programs
- 380 Rehabilitation Aid
- 380 Environmental Control
- 380 Evaluation of Rehabilitation Technology
- 381 Arm-Powered Bicycle for the Disabled
- 382 Tandem Bicycles for Disabled and Able-Bodied to Ride Together
- 383 Information Technology in Rehabilitation Engineering
- 383 Technology to Enhance Independence of Physically Disabled School Children
- 384 Supported Employment
- 384 Rural Rehabilitation Technologies Database
- 385 Interpersonal Problem-Solving by the Mentally Ill: Video-Assisted Technology for Training Social Skills
- 385 Computerized Treatment of Acquired Reading Disorders
- 386 A Program for Evaluating the Dysvascular Patient
- 387 Training Schizophrenic Patients in Medication Management
- 388 Training Chronic Mental Patients in Social and Independent Living Skills
- 389 Dissemination of Rehabilitation Technologies
- 390 Development of a Life Satisfaction Scale Applicable for People with Severe Disabilities

XVI. Miscellaneous

- 392 Rehabilitation of Neurogenic Communicative Disorders in Remote Settings
- 392 A Manual for the Development of a Program in Rehabilitation Medicine in a Ghetto Hospital
- 393 Diabetic Neurotrophic Ulceration: Screening and Prevention Utilizing Aesthesiometry
- 394 Thermographic/Spectroscopic Comparison of Soaks, Exercise, and Trental TM on Diabetic Feet
- 394 Development of a Sensory Substitution System for the Insensate Foot
- 395 Information Resources
- 396 HSRI Mental Health Strategic Planning and Resource Allocation Model
- 396 Social Skills Training for Older and Younger Persons with Severe Physical Disabilities
- 397 Family Factors and Work Adjustment of Handicapped Mexican-Americans
- 398 Laser Removal of Tattoos and Port Wine Stains
- 399 The Research and Training Center on Independent Living (RTC/IL)
- 401 Growth and Bone Haemodynamic Responses to Castration in Male Rats: Reversibility by Testosterone
- 402 Sponsoring Agencies and Organizations
- 425 Contributor Index

I. Amputations and Limb Prostheses

A. General

Thermographic and Electromyographic Correlates of Stump and Phantom Limb Pain

Richard A. Sherman, Ph.D. and Glenda M. Bruno, M.S.

D.D. Eisenhower Army Medical Center, Fort Gordon, GA 30905 and Medical Research Service, Veterans Administration Medical Center, Augusta, GA 30910

Sponsor: VA Rehabilitation Research and Development Service and D.D. Eisenhower Army Medical Center

Progress—Thirty amputees reporting stump and/or phantom limb pain were recorded using thermographic measures of near-surface body heat and surface electromyographic measures of muscle tension. Each subject was recorded between two and four times while reporting varied pain intensities. A consistent inverse relationship between intensity of pain and stump

temperature relative to the intact limb occurred for only the burning, throbbing, and tingling descriptions of phantom limb pain and stump pain, but not for other descriptions. For subjects giving these descriptions of pain, increasing muscle tension resulted in a decrease in blood flow and an increase in pain.

Psychological Factors Influencing Chronic Phantom Limb Pain: Analysis of the Literature and a Survey of Locus of Control

Richard A. Sherman, Ph.D.; Crystal J. Sherman, M.S.; Glenda M. Bruno, M.S.

D.D. Eisenhower Army Medical Center, Fort Gordon, GA 30905; Department of Neurology, Medical College of Georgia; and Medical Research Service, Veterans Administration Medical Center, Augusta, GA 30910

Sponsor: VA Rehabilitation Research and Development Service and D.D. Eisenhower Army Medical Center

Progress—We have reanalyzed the behavioral literature concerning chronic phantom limb pain in order to determine the role of psychological factors in initiating and controlling the intensity of its episodes. We also surveyed a group of amputee veterans to determine the role which locus of control has in the report of phantom limb pain and its characteristics. Some of the behavioral literature presents an inaccurate picture of amputees who have phantom pain. This happened because much of the data were gathered from those amputees requesting treatment for phantom pain who were referred to mental health professionals.

Results—There was no relationship between locus of control and any aspect of phantom pain. We conclude that phantom pain is similar to other chronic pain syndromes in that episodes are greatly influenced by psychological factors such as stress and depression. Repeated requests for treatment are influenced by personality structure. There is no convincing evidence that major personality disorders are important in the etiology of chronic phantom pain. Nor is there evidence that such personality disorders are more prevalent among those amputees reporting phantom pain than among those who do not report it.

Fluorometric Quantification of Low-Dose Fluorescein Delivery to Predict Amputation Healing

David G. Silverman, M.D.; Andrew B. Roberts, M.D.; Cheryl A Reilly, R.N.; David A. Brousseau, B.A.; Karin J. Norton, B.A.; Earl Bartley, B.A.; Gordon R. Neufeld, M.D.

Department of Anesthesia, University of Pennsylvania School of Medicine; Division of Vascular Surgery, Medical College of Pennsylvania, Philadelphia; and Division of Anesthesia Research, Philadelphia Veterans Administration Medical Center 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This retrospective study measured the delivery of fluorescein to skin by fiberoptic fluorometry to determine the healing potential of an amputation site. Fluorometry employs a dual-channel fiberoptic light guide; one channel transmits blue light to excite the fluorescein in the skin under study, and the other transmits the emitted fluorescence from the skin to a photomultiplier tube where it is measured. Ten minutes after intravenous administration of sodium fluorescein (4-8 mg/kg), fluorometric readings were obtained at more than 100 skin sites.

Progress—In the 86 cases without preoperative cellulitis at the site of amputation, preoperative fluorometry clearly distinguished between heal-

ing and nonhealing sites. Healing sites average 76 percent of the fluorescence of a healthy reference area (Dye Fluorescence Index or DFI = 76), while failing sites averaged only 27 percent ($p < 0.01$ by analysis of variance). In all but one case where the DFI was greater than 42, the amputation healed. In all cases where the DFI was less than 38, the amputation failed.

The technique maintained its high accuracy in diabetic patients and for distal amputations. However, in 12 cases it was not accurate at sites of active cellulitis. There were no significant adverse effects from the slow injection of the low dose of fluorescein employed for this technique. We conclude that fluorometry is an effective means of predicting healing in patients undergoing amputation.

Development of Materials for Percutaneous Passage

Thomas A. Krouskop, Ph.D.; Harlan Brown, Ph.D.; David Judge, M.D.

The Institute for Rehabilitation and Research, Texas Medical Center, Houston, TX 77225

Sponsor: National Institute of Handicapped Research

Purpose—This study has the following objectives: 1) to examine whether percutaneous devices fabricated from porous vitreous carbon can function satisfactorily *in vivo* over extended periods of time; 2) to determine whether the interface formed between dermal tissue and porous carbon devices is capable of preventing the infiltration of bacteria present at the exit site; and 3) to evaluate the effects of cyclic loading upon wound healing, tissue ingrowth, and the long-term performance of the percutaneous implant.

Progress—During this report period, results of the work have been very promising. The overall goal of developing a material system that can

be used for creating long-term percutaneous passageways seems feasible. A preoperative conditioning program has been developed for use with the pigs to reduce the need for drugs during handling and inspection of the implant sites. The protective vests have been fabricated and modified for pigs to provide an effective mechanism for preventing the animal from rolling on the implants and yet provide easy access to the implant for daily inspection and infection control.

Baseline information on the time required for wound healing in the miniature swine has been established and is available for the study that will be conducted during the third year as well as the bacteriological studies which are

currently being performed.

Histopathology exams have been accomplished on the implants which have been excised from the rabbits and pigs. Tissue ingrowth into the pores of the prostheses has occurred and there is a mild chronic inflammatory response to the prostheses. There is light to moderate fibrosis around the implants. There is no histological evidence of infection in the tissue surrounding the implants.

Bacteriology studies have been conducted on percutaneous devices implanted in miniature swine. The implants were permitted to heal for 4 weeks during which time daily visual inspections were made to detect sinus tract formation or marsupialization. During the 4th week after the devices were implanted, swab cultures were taken to describe the bacterial flora present at the implant site. The bacteria recovered represented typical flora that would be expected from skin cultures that might be

taken from healthy animals.

During the 5th week after implantation two implants on each of the swine were given a very aggressive bacterial pathogenesis challenge. Saline containing 100,000 cells per ml each of *S. aureus* and *Ps. aeruginosa* were painted on the test devices and cultures were collected 24 and 72 hours later.

Results—These studies have shown that percutaneous devices can be implanted in both rabbits and miniature swine successfully and that the implant sites resist infection with normal flora bacteria for as long as 5 weeks. The pathogen challenge studies show that although superficial surface colonization and infection may occur after application of the pathogens, penetration of the challenge pathogens into the tissue under the implanted devices did not occur.

Myoelectric Controller for Orthotic/Prosthetic Systems

Michael W. Keith, M.D. and P. Hunter Peckham, Ph.D.
Case Western Reserve University, Cleveland, OH 44109

Sponsor: *National Institutes of Health*

Purpose—The aim of this project is to develop the techniques and instrumentation necessary for the high spinal cord injury and amputee population to obtain multiple command control signals, for use in activation of upper extremity orthotic and prosthetic appliances. Emphasis is placed on producing command signals that are proportional in nature and with sufficiently high signal-to-noise ratios for the execution of controlled movements. As a result of this research, we will develop a command control scheme which optimizes the performance and fidelity of the output device.

Progress—The focus of this project has been the development of the implanted circuitry of

the telemetry device. The design has been completed and the central component, a semi-custom CMOS integrated circuit has been fabricated. The device will process up to eight channels of information at a total rate of 11 KHz. Powering and transmitting of the device is via radio frequency energy. The transmitter design is nearing completion.

Future Plans—The telemetry circuitry layout and fabrication will be completed and packaged in already developed and tested titanium enclosures. We plan to evaluate the reliability and performance of the device in a dog animal model.

B. Lower Limb

1. General

Computer-Aided Alignment of Lower Limb Prostheses and "Expert" Systems

Robert L. Van Vorhis, M.S. and Lew Leibowitz

Prosthetics Research Laboratory, Northwestern University, Chicago, IL 60611

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Alignment of a lower limb prosthesis when an amputee walks is largely a subjective exercise that is guided by certain principles or rules that have developed over the years. It is a procedure that requires knowledge, judgement, and experience. Our objective is to develop quantitative tools which we can use to understand the alignment process better in order to improve the alignment procedure and thereby improve prosthetic management of lower limb amputees.

The first part of our plan to gain understanding of the alignment process is to develop tools through which we can quantify and represent, in an objective domain, the subjective rules that characterize the alignment protocol of experienced prosthetists. This quantification will be carried out with a movement-analysis system, the CODA-3. Since alignment is now carried out by visual observation, the motion analysis equipment should be able to gather, in greater detail, the information now gathered visually and used by prosthetists for dynamic alignment procedures.

During the alignment process, the CODA-3 Movement Monitoring Instrument will be used in two modes. These modes may exist simultaneously. During one mode, the real-time, high accuracy feature of the CODA (300 Hz sampling of landmark 3D-Cartesian coordinate position, accuracies on the order of plus or minus 0.3 mm) will be used to assist the prosthetist in establishing a particular limb alignment state (the socket-foot relationship consisting of three position and three orientation degrees-of-freedom). In the second mode, the CODA-3 will be

used in a more traditional "observational" mode to evaluate the gait characteristics at that particular alignment state. By making these quantitative tools accessible (both measuring state of alignment and facilitating the display of quantitative information pertinent to amputee performance) the prosthetist will be able to carry out the alignment process in a more objective and quantified domain.

To understand the alignment process and to establish a functional relationship between alignment variables and those gait variables which strongly influence alignment, the motion analysis tools will be used in a study involving ten below-knee amputees who are "good" walkers and two prosthetists who are considered to be "expert." This study will proceed by comparing pertinent measured walking parameters established during walking within the "range" of good alignment for each amputee/prosthetist combination, with these same parameters measured while walking in an alignment state which has resulted in a prosthetist identifiable "gait deviation." Since alignment is a highly individualized process these studies will be self-referential while the feasibility of using this approach is tested.

In the second part of our plan, we will organize and focus our thoughts by establishment of a so-called "expert" system for alignment. This is a knowledge-based computer system based upon expert prosthetist knowledge and experience with alignment. By coupling rules of thumb and heuristics with mathematical models based on physical principles in an expert system framework, our understanding is

not only formalized and can be recalled, but potentially, new knowledge can be compared with our present understanding of alignment and added to the expert system, if appropriate. For example, once we have established a reasonable understanding regarding alignment state, prosthetist observable gait variables, and the correlating types of amputee motor strategies during walking, additional parameters such as the floor reactions and joint moments can be studied from within the context of an identified amputee walking strategy.

Progress—Our present work relates to the development of quantitative measurement tools and information displays which make the full potential of these tools accessible to the prosthetist. A computer system integrating the CODA-3 and two biomechanics platforms (forceplates) has been developed. Our computer system has been designed with the potential for also acquiring and storing EMG data. While

the present CODA-3 model we possess needs to be updated to realize its potential, we expect this to be done in the near future, not causing significant project delays.

Software allowing real-time interactive or post-processed displays of the socket-foot relationship has been partially completed. The facility for overlaying data (real-time or post-processed) on video images of amputee activity (floor-reaction, EMG, kinematic information, etc.) is also currently in progress. We will soon be mounting our biomechanics platforms permanently within a raised walkway to allow the walking-trials portions of this project to proceed on a continuing basis.

It is hoped that our understanding of objective alignment criteria will mature in the future to the point that the prosthetist, guided by the expert system, can utilize the objective measurement tools to quickly and accurately arrive at an acceptable alignment state.

Automated Fabrication of Lower Extremity Prosthetic Sockets

William A. Blocker, M.D.; Thomas A. Krouskop, Ph.D.; Dale R. Dougherty, B.S.
Veterans Administration Medical Center and Baylor College of Medicine, Houston, TX 77211
Sponsor: VA Rehabilitation Research and Development Service

Purpose—The goal of this project has been to demonstrate the technical and economic feasibility of using CAD/CAM techniques to fabricate sockets for above-knee amputees.

Progress—During this report period, a mechanical shape sensing system has been fully automated and is capable of collecting circumferential data that are at least as accurate as the data collected by prosthetists and the instrument is capable of providing both overall and segmental shape information that is not easily obtainable when using conventional casting procedures.

The interface pressure loading on the stump has been defined and characterized using a series of pneumatic pressure sensors. This activity has demonstrated that the most proximal 4-6 inches of the stump is where most of the differentiation occurs when the cast is

rectified. The interface pressures in this region range between 90 and 120 mm Hg when the socket is comfortable. When the interface pressure exceeds 150 mm Hg the socket is perceived to be uncomfortable by the user. Below the top 6 inches of the socket the interface pressure remains relatively uniform over the surface of the stump and has an average magnitude of 60 mm Hg. An ultrasonic based tissue property measuring system has been finalized and is being used to collect modulus information to characterize the soft tissue which comprises an amputee's stump.

Tissue property data collected with the ultrasound based system have been compared with tissue properties collected using the more conventional measuring systems and the data are in good agreement. The ultrasound system is capable of detecting stiffness changes due to edema and muscle contraction.

Two sockets for above-knee prostheses have been fabricated using the algorithm developed in the project and have been fitted with no modification by the prosthetist. One of these legs has been worn for 6 months and is now not being worn because the user has lost 20 pounds and the socket is loose. The second leg has been used for approximately 1 month with no negative indications at this time.

The technology which has been developed in this project has proven the technical feasibility of using CAD/CAM techniques to emulate the socket casting process that is currently used by prosthetists. It remains to be demonstrated that the laboratory prototype instrumentation can be transferred into clinically reliable tools. Moreover, the patient population who can be best served by using this process must be defined empirically through clinical use.

Using the ANSYS finite element code, a model for the above-knee stump has been developed that is capable of calculating the shape of

the stump that will provide the desired surface loading characteristics as a function of the material properties of the soft tissue comprising the stump. The model has been developed and refined so that it now runs on the Cyber 175 computer in less than 25 minutes.

Software has been developed that enables us to take the displacement solution from the ANSYS analysis and interpolates the data so that an input file can be created that is compatible with the requirements of any numerical control (NC) machine programmer. This software makes use of an interpretation scheme developed by Akima which can be used for both closed curves and open curves. This technique has been shown to be more accurate than the Spline functions that are customarily used to fit the data that generate the tool pattern for an NC machine. This software is modular in nature and can be used with a variety of main frame computers or the larger personal computers, such as the AT&T 6300.

CAD/CAM of Lower Extremity Prostheses: The San Antonio System

Virgil Faulkner, C.P.O.; Nicolas Walsh, M.D.; Norman Gall, M.D.

The University of Texas Health Science Center at San Antonio, Department of Physical Medicine and Rehabilitation, San Antonio, TX 78284

Sponsor: *In-house funding*

Progress—The Rehabilitation Engineering Lab (REL) at the University of Texas Health Science Center at San Antonio is currently working on a system for computer-aided design and computer-aided manufacture of prostheses. This system, when perfected, will offer the amputee an opportunity for optimal prosthetic socket fit. It will also provide computer analysis of current socket design for research purposes.

The project is divided into three sections:

1) The development of a shape sensing device. There are four subdivisions of this section: ultrasound, radiant image, digitized, and video images.

2) The development of a user-friendly software package capable of running on a micro-computer. This section has two subdivisions. One is a software packaged interfaced with the shape sensing device that will allow the opera-

tor to custom design a prosthetic socket. Two, a software package that will interface with the computer-aided designed package for computer-aided manufacture of the prosthetic socket from the computer-generated data.

3) The development of an automatic computer-operated alignment device that can be permanently mounted in the prostheses.

Results—The shape sensing devices are described in other progress reports. The computer program for prosthetic design is approximately 80 percent complete and the program for control of the computer-operated milling machine is 95 percent complete. The REL is actively seeking research funds to accelerate this project. Currently, the project is a part-time, in-house funded study.

Ultrasound as an Aid to Prosthetic Socket Design

Virgil Faulkner, C.P.O.; Nicolas Walsh, M.D.; Norman Gall, M.D.

The University of Texas Health Science Center at San Antonio, Department of Physical Medicine and Rehabilitation, San Antonio, TX 78284

Sponsor: *In-house funding*

Progress—The ultrasound shape sensing device currently in use at the San Antonio Rehabilitation Engineering Lab (REL) is capable of producing an accurate computer-generated database topographical image of a residual limb. The system is composed of two subsystems: the ultrasound and analog electronics subsystem; and, the computer-based data acquisition and control subsystem.

An image of a patient's residual limb is automatically generated in five to ten minutes. The data representing the topological shape of the limb are stored on the computer's hard disk unit as a set of X, Y, and Z coordinates. This data may then be retrieved, viewed, and modified by a number of custom and commercially available application programs. One such program would allow a prosthetist to easily modify the data so as to reshape the topological surface according to normal prosthetic principles. The final version of the data may be sent via modem or floppy disk to a machine shop where

a socket mold could be manufactured on a computer numerically controlled milling machine. One advantage of a computer-based system is that the original and modified data are permanently stored. Thus, if there is a problem with the fit of the first socket, or atrophy of the residual limb over time, then corrections may be made using the computer (rather than re-scanning the patient).

Results—We are currently using an AT&T 6300 (IBM compatible) microcomputer to acquire data and control the imaging system. However, any computer with a parallel data port, a GPIB interface, and graphics capabilities may be used (if appropriate software is available). The REL is actively seeking funding to improve the USSD so that it can detect and image bone, image residuals up to 20 inches in length, and then acquire the image in five seconds or less real-time.

Computerized Tomography as an Aid to Prosthetic Socket Design

Virgil Faulkner, C.P.O.; Nicolas Walsh, M.D.; Norman Gall, M.D.

The University of Texas Health Science Center at San Antonio, Department of Physical Medicine and Rehabilitation, San Antonio, TX 78284

Sponsor: *In-house funding*

Progress—The Rehabilitation Engineering Lab (REL) at the University of Texas Health Science Center in San Antonio recently acquired a computer system developed by Contour Medical Systems, Inc., of Mountainview, CA. This machine, the CEMAX 1000, can reconstruct three-dimensional images of tissue and bone from an analysis of computed tomography data. This system is used as a shape sensing device to capture the exact topographical image of an amputee's residual limb. The CEMAX 1000 has software written for it which allows the research prosthetist to modify the CT scan in

much the same way as he or she would modify a positive model.

This modified image is then transmitted to Contour Medical System's computer-controlled milling machine for positive model manufacture. The model is then returned to the REL where a transparent check socket is fabricated.

CT data scans of an amputee's residual limb provide an excellent quantitative record. The CEMAX 1000 also provides a system that allows the operator to quickly and accurately reconfigure a three-dimensional computer image of the residual limb for prosthetic socket

design and manufacture.

Future Plans—The next step in this project

proposes the milling of a below-knee prosthetic socket by Contour Medical Systems bypassing the positive model step.

The 3-D Digitizer as an Aid to Prosthetic Socket Design ---

Virgil Faulkner, C.P.O.; Nicolas Walsh, M.D.; Norman Gall, M.D.

The University of Texas Health Science Center at San Antonio, Department of Physical Medicine and Rehabilitation, San Antonio, TX 78284

Sponsor: *In-house funding*

Purpose—The 3-D digitizer currently used by the San Antonio Rehabilitation Engineering Laboratory is the "Preceptor TM." It is a precision electromechanical unit that allows direct spatial digitization of solid three-dimensional objects.

In operation the stylus at the end of the Preceptor's arm is tracked over a solid object such as a negative cast of the amputee's residual limb. A precision potentiometer housed in the extension arm computes the X, Y, and Z coordinates based on the angle of rotation and known arm length that reaches to 17 inches.

Utilizing the "Advanced Space Graphics TM", a three-dimensional graphic software

package which can be used for quickly creating and manipulating images in three dimensions, we can produce wire frame objects and line sketches that can be quickly and easily modified and stored for future use.

Progress—The REL has developed a companion software package that allows us to digitize a negative cast of the amputee's residual limb after we have split the cast in half. After digitization, the two halves are reunited and sent via telephone modem to a central fabrication unit. Here socket manufacture takes place utilizing computer-controlled milling machines.

Study of Alignment in Lower Limb Prostheses ---

S.E. Solomonidis and J.P. Paul

University of Strathclyde, Wolfson Centre, Glasgow G4 ONW Scotland

Sponsor: *Scottish Home and Health Department*

Purpose—The 1985 issue of *Rehabilitation R&D Progress Reports* gave an outline of the aims and methodology employed in this project. This work is still in progress. The investigation is a systematic study of the lower limb alignment parameters in order to gain an understanding of the biomechanical factors which make a limb configuration acceptable to the amputee.

Progress—In the experiments carried out, three prostheses were involved in the majority of 183 below-knee and 100 above-knee fittings. It was found that each patient was satisfied by a range of alignments and the range for each amputee was established. The study also

showed that, on average, an amputee can tolerate a variation of ± 5 degrees in socket flexion, ± 25 mm in socket forward set, ± 4 degrees lateral tilt and ± 20 mm socket set-out. From the data acquired it was possible to arrive at recommendations for bench alignment and for the range of adjustment required to be incorporated into the design of alignment units for both below- and above-knee prostheses. The results of this part of the investigation have been published in the *Journal of Rehabilitation Research and Development*, Vol. 23, No. 2.

A study of the effect of various acceptable alignments on an amputee's gait patterns was made using kinetic and kinematic measurements. It was found that for an amputee walk-

ing on a certain prosthesis there exists a step-to-step variation in the various gait parameters. This variation must be quantified before any attempt is made to obtain comparisons of gait parameters resulting from various acceptable alignments.

Taking the step-to-step variations into account it was established that the alignment of a prosthesis has a direct effect on the amputee's gait pattern. Although small differences in gait pattern can be detected, using an analysis of the kinetic parameters alone, for a complete understanding of amputee locomotion both kinetic and kinematic information is necessary.

Using biomechanical considerations, it was found that it was possible to select the most appropriate alignment from a number of acceptable alignments.

Preliminary Results—The work so far carried out has indicated that a considerable amount of work is still necessary before a proper understanding of the biomechanics of amputee locomotion and the effects of alignment changes on prosthetic gait can be obtained. Further investigations incorporating the study of the contralateral side and the movements of the trunk are planned.

The Effect on Gait Using Various Ankle-Foot Devices

Frank L. Golbranson, M.D.; Roy W. Wirta, BSME; Eric J. Kuncir, MSBE
VA Medical Center, San Diego, CA 92161

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this study is to determine criteria for the prescription of prosthetic ankle-foot devices. The study examines relationships between physical characteristics of amputees and locomotion performances when using different ankle-foot devices on level and nonlevel smooth surfaces. Five different configurations under investigation are: 1) SACH, 2) SAFE, 3) articulated single axis, 4) multi-axial Greissinger, and 5) SEATTLE.

Progress—The design, construction, and testing of special equipment needed to conduct the study were completed: a) a ramp incline/decline apparatus to test locomotion while accommodating ascent/descent of a ramp and a lateral incline to one side and to the other, b) an accelerometer pack to attach to the prosthesis for measuring angular accelerations in two planes, and c) special foot switches. In addition, a manually actuated, spring loaded horizontal pendulum was constructed and used to cali-

brate the accelerometer pack. Equipment used in a concurrent grant titled "Analysis of Below-Knee Suspension Systems: Effect on Gait," including knee electrogoniometers, a gimbal mounted biaxial accelerometer, and a tachometer are used in this study. A test protocol was developed and testing of amputees was started. Data treatment will be a comparative biomechanical analysis and will focus on identifying and interpreting anomalies in the locomotive performances of the amputees which are expected to relate to effects resulting, for example, from the different ankle-foot devices and the length of the stump. Computer programs and computing procedures developed for the suspension study have been modified and adapted for use in this study.

Future Plans—The five ankle-foot devices will be tested on 20 unilateral below-knee amputees, results will then be analyzed, and a report will be written on the findings.

Survey of Design Criteria for Prosthetic Knee and Ankle Joints

S.E. Solomonidis; P.E.Y. Yacoob; J.P. Paul

University of Strathclyde, Bioengineering Unit, Wolfson Centre, Glasgow G4 ONW, Scotland

Sponsor: *Scottish Home and Health Department*

Purpose—Although many knee mechanisms, some incorporating ingenious features, have been designed to provide stance phased stability and swing phased control for above-knee prostheses, apart from very few exceptions, most of these have been rejected by the amputee. The only mechanisms that have had some success have been the very simple types despite their limitations. A reason for this failure may be due to the lack of a complete specification of the design requirements or due to inability of the designer to satisfy all criteria. In order to investigate the situation, a preliminary study was undertaken and briefly described in the *VA Rehabilitation R&D Progress Reports* of 1985.

Progress—The survey has been extended to involve some 150 amputees. Basically the aim is to obtain the amputee's opinions towards his

prosthesis taking into account function, comfort, and cosmetic restoration aspects. The survey, which takes the form of a structured conversation, attempts to obtain answers to questions relating to the following: comfort, integration, and acceptance of the prosthesis; determination of problem areas; phantom pains and conditions under which they exist; physical characteristics of the prosthesis (e.g., mass, alignment); performance during ambulation and other daily activities; performance of the artificial knee and ankle joints; and, determination of desirable features to be incorporated in future prostheses. The opinions of prosthetists and clinicians on the above topics also are being sought.

It is hoped that this investigation will provide useful data for the formulation of criteria for the design of enhanced prosthetic knee and ankle joints.

Fiberoptic Fluorometry as a Useful Adjunct in Determining Lower Extremity Amputation Level

Andrew B. Roberts, M.D.; Cheryl A. Reilly, R.N., B.S.N.; Kalind R. Bakshi, M.D.; David G. Silverman, M.D.; Gordon R. Neufeld, M.D.

Division of Vascular Surgery, Medical College of Pennsylvania; Department of Anesthesia, University of Pennsylvania School of Medicine; and, Division of Anesthesia Research, Veterans Administration Medical Center, Philadelphia, PA 19129

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—Preoperative prediction of amputation healing in the ischemic lower extremity remains difficult. When attempting to maximize the patient's rehabilitative potential by performing the amputation as distally as possible, amputation failures have been frequent. Quantitative fluorometry is a method for evaluating cutaneous perfusion following intravenous administration of the dye sodium fluorescein. Using a well-perfused reference site on the upper extremity, a retrospective study predicted amputation failure when the fluorescein delivery at the amputation site was less than 38

percent of the reference site, and success when it was greater than 42 percent (see abstract: Silverman, et al., *Fluorometric quantification of low dose fluorescein delivery to predict amputation healing*).

Progress—In this prospective study, 48 patients underwent fiberoptic fluorometry before undergoing 65 amputations, and preoperative predictions of amputation healing were made. Four amputations were excluded because the extremities were either edematous, cellulitic, or had abnormally thickened skin. In our experience,

the presence of any of these factors reduces the predictive value of the test. Of the remaining 61 amputations, four had fluorescein ratios of less than 38 percent and these amputations failed. Fifty-two amputations had ratios greater than 42 percent, and 47 (90 percent) healed.

Preliminary Results—The test had a sensitivity

of 100 percent, a specificity of 44 percent, and a predictive value of 91 percent. We conclude that fiberoptic fluorometry is a useful adjunct to the clinical judgement of the surgeon, when he is attempting to optimize his patient's rehabilitative potential while avoiding amputation failures.

Determining the Need or Level of Amputation by Assessing Nutritive Skin Blood Flow

Gordon R. Neufeld, M.D.; Andrew B. Roberts, M.D.; Cheryl A. Reilly, R.N., B.S.N.; Stephen R. Galante, B.S., Ch.E.; Joyce Whang, B.S., Ch.E.; James E. Baumgardner, M.D., Ph.D.; David J. Graves, Sc.D.; John A. Quinn, Ph.D.; David Silverman, M.D.

Veterans Administration Medical Center, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Adequate nutritive skin blood flow is the prime requirement for the healing of amputation sites in patients with peripheral vascular disease. We developed a multidisciplinary approach to the measurement of skin blood flow and the clinical evaluation of these patients. The purpose of the studies was: 1) to develop an accurate-clinical test of skin blood flow which was predictive of skin wound healing in patients coming to amputation; 2) to develop a quantitative measurement of skin blood flow for comparison to existing methods; and 3) to compare and correlate several different skin blood flow methods including quantitative fluorometry, xenon washout, helium flux, and laser doppler velocimetry.

Progress—

1) *Clinical Studies of Fluorometry*. We have completed studies of quantitative fluorometry in a large group of patients coming to amputation. In a retrospective study of 62 patients we found that the mean level of fluorescein delivered to the amputation site was 79 ± 37 percent of a well perfused reference area in all patients whose amputations healed. The mean fluorescein delivery to non-healing sites was 27 ± 14 percent. Using criteria developed from this study, we found in a prospective investigation, that the fluorescein test had a sensitivity of 100 percent, a specificity of 44 percent, and a

predictive value of 91 percent. We find fiberoptic fluorometry to be a useful adjunct to clinical judgement in patients requiring amputations.

2) *Evaluation of Helium Flux for the Measurement of Skin Blood Flow*. We set up the helium flux measurement of skin blood flow developed by Baumgardner, et al. (*J Appl Physiol* 58:1545, 1985). We measured the helium flux through the skin with a small heated probe at several temperatures in the range between 32 degrees C and 42 degrees C. The diffusional resistance of the skin to helium was minimized (assumed equal to zero) by skin stripping with adhesive tape. We found a linear relationship between helium flux determined blood flow and temperature of the skin probe in normal subjects. The average blood flow at 33 degrees C was 2.4 ± 1.1 and at 42 degrees C was 5.8 ± 1.6 mls/min cm².

3) *Comparison of Skin Blood Flow Measurement Techniques*. In preliminary studies of fiberoptic fluorometry versus laser doppler velocimetry, we find a close correlation between relative skin blood flow by fluorometry and the increase in laser doppler signal to an increase in laser probe temperature. The use of a temperature "challenge" with the laser doppler provides consistent data between subjects and skin sites. We found a linear relationship between blood flow determined by helium flux and Xe¹³³ washout. We compared helium flux

blood flow measurements to the laser doppler at several skin temperatures and found the laser to give non-linear response to rising temperature (as described by others) while the helium flux determination yields a linear response over the same temperature range.

Future Plans—While the measurement of skin blood flow by helium flux is the most reliable quantitative method we have tested so far, it is slow and requires that the stratum corneum be removed prior to the study. We are developing

a new method to measure stratum corneum diffusive resistance which hopefully will eliminate the need for skin stripping. Studies are planned to examine the transport of other gases across the skin including oxygen, carbon dioxide, argon, and xenon to further characterize the relationships among blood flow, diffusive resistance, solubility, and metabolic activity. In addition, we are developing new techniques for rapid comparison of laser doppler measurements which do not require a change in probe temperature.

Aerobic Training Improves Cardiovascular Fitness and Increases Efficiency of Walking in Lower Limb Amputees

Kenneth H. Pitetti, Ph.D.; Peter G. Snell, Ph.D.; James Stray-Gundersen, M.D.; Frank A. Gottschalk, M.D., FRCS Ed. Dallas Veterans Administration Medical Center and St. Paul/UTHSCD Human Performance Center, Dallas, TX 75235

Sponsor: VA Rehabilitation Research and Development Service and The Special Team for Amputation and Mobility Prosthetics/Orthotics, Dallas VA Medical Center

Progress—Ten lower limb amputees were studied before and after a 15-week aerobic conditioning program to determine if regular exercise involving the upper limbs and the remaining lower limb(s) would improve their cardiovascular fitness and reduce the effort of walking. Each subject exercised on a Schwinn Air-Dyne ergometer (SAE) regularly during each week at 60-80 percent of their estimated maximal heart rate (HR). A maximum exercise test on the ergometer and a treadmill walking test

were administered before and after training. After training there was a 27 percent increase in maximal exercise capacity on the SAE as well as significantly lower values in heart rate and oxygen consumption (ml/min/kg) during treadmill walking at various inclined grades, whereas there were no changes in control amputees. Aerobic conditioning of the lower limb amputee was shown to not only improve cardiovascular fitness but increase their walking efficiency as well.

Relation Between Cardiac Condition of Leg Amputees and the Success of Their Prosthetic Rehabilitation

J.A. van Alste; H.E.P. Cruts; G. Zilvold; H.B.K. Boom; J. de Vries; K. Huisman

Biomedical Engineering Division, Twente University of Technology, 7500 AH Enschede, The Netherlands

Sponsor: Dutch Heart Foundation

Purpose—Most leg amputations are performed because of peripheral vascular insufficiency. In patients who are over 50 years atherosclerosis may have caused changes in the brain and heart. When prescribing a prosthetic training program to the leg amputee it must be considered whether the patient is capable of undergoing the physical and emotional stress of the training involved.

The aim of this study was to investigate the influence of the cardiac status on the rehabilitation process and to assess cardiac loads provoked during prosthetic training exercises.

Progress—Cardiac loads were estimated from the results of automatic analysis of the ECG: heart rate responses (as a measure of cardiac load), morphological changes (ST-segment anal-

ysis), and arrhythmia detection (as possible indicators for overloading of the heart). An integral system for ECG-analysis during rehabilitative exercises was developed.

Of the 39 leg amputees taking part in the study two-thirds had a history of previous cardiac disease. All performed a graded exercise test (rowing ergometry) within one month after starting the rehabilitation to assess their cardiac response to exercise and to evaluate the cardiac status. In 87 percent of the patients the prosthetic training was completed successfully. The functional rehabilitation result showed relationships to age and peak workload in the initial exercise test. The level of amputation had no prognostic value for the functional rehabilitation result. It was noted that total rehabilitation time was strongly related to the progress of wound healing.

Heart rate response was obtained during one leg walking, walking with a preliminary

prosthesis, and prosthetic walking. The averaged peak heart rate values were not different, whereas the steady-state heart rate level was lower during walking with a preliminary prosthesis and the definitive prosthesis than during one leg walking. The walking speed and walking distance increased with the stage of rehabilitation. Monthly repetition of the graded exercise test showed that during normal rehabilitation no overall improvement of a patient's cardiac condition is to be expected.

Results—No excessive cardiac loads are to be expected when the leg amputees with peripheral vascular disease are allowed to choose their own walking speed during training exercises. In patients with a low peak workload during the exercise test it is advised that ECG be monitored frequently, especially when the patients are exercised in one leg walking.

Limb Viability: Vascular Reconstruction and Amputation Surgery

James M. Malone, M.D.; Gary Anderson, B.A.; Jeff Seery; Kenneth C. Mulrea, BSEE, Ph.D.; Robert E. Henry, M.D.
Veterans Administration Medical Center, Tucson, AZ 85723

Sponsor: VA Rehabilitation Research and Development Service

Progress—Work on the limb viability project is divided into three main components: 1) evaluation of new instruments and techniques for assessment of limb viability with vascular reconstruction and the assessment of objective preoperative amputation level selection; 2) evaluation of the role of education in the prevention of amputations in high risk diabetic patients; and 3) evaluation of regional hyperbaric oxygen as an adjunct to amputation stump and/or wound healing.

The limb viability studies have involved head-to-head comparison between intradermal Xenon¹³³ skin blood flow techniques, transcutaneous oxygen, transcutaneous carbon dioxide, laser doppler, and doppler derived ankle and segmental limb blood pressures. In a prospective evaluation which is currently under study, the preliminary results show that both transcutaneous oxygen and transcutaneous CO₂ provide statistically valid end points for the preop-

erative determination of amputation level selection. Neither the laser doppler, ankle/arm blood pressures, nor Xenon¹³³ had statistical reliability. In addition, intraoperative monitoring with transcutaneous oxygen and transcutaneous carbon dioxide are suggesting that those techniques have utility for intraoperative and postoperative monitoring with respect to the ability to predict both short-term and long-term graft patency. Material on both the amputation level selection data and the intraoperative monitoring have been submitted to meetings for consideration for presentation; however, at this time none of the data have been accepted for publication.

Preliminary Results—A prospective evaluation of the role of education in prevention of recurrent foot ulceration, foot infection, or amputation in high risk diabetic patients has just been completed. The data are currently undergoing

statistical analysis, but the preliminary evaluation suggests that patient education can produce a three-fold reduction in the incidence of limb amputation in diabetic patients with foot infection, foot ulceration, or contralateral limb amputation. When analysis of the data is completed, a formal manuscript will be submitted for publication. In addition, it would be anticipated that these preliminary data need verification by a larger study, possibly a VA-wide or S.T.A.M.P. evaluation.

The final area of research has involved an evaluation of the use of regional hyperbaric oxygen in an effort to obtain healing of non-reconstructable ischemic limbs. The project involved the assessment of transcutaneous

oxygen values before and after treatment with regional hyperbaric therapy. Although there are individual patients in whom hyperbaric oxygen has been of help, it is impossible to predict beforehand which patients are likely to benefit from therapy.

Future Plans—During the upcoming year we plan to expand our prospective study of tests on limb viability, to expand our educational diabetic program, and complete and publish our findings with hyperbaric oxygen. In addition, we anticipate finalizing development of a new noninvasive tool for the determination of skin blood pressure and tissue oxygen saturation.

Use of Cutaneous Pressure Photoplethysmography in Managing Peripheral Vascular Occlusive Disease

Bok Y. Lee, M.D. and Lee E. Ostrander, Ph.D.

Veterans Administration Medical Center, Castle Point, NY 12511 and Rensselaer Polytechnic Institute, Troy, NY 12181

Sponsor: VA Rehabilitation Research and Development Service

Progress—A technique for local measurement of cutaneous perfusion pressure (CPP) has been developed which utilizes photoplethysmographic measurement during local pressure application to the skin. A total of 225 limbs have been studied to evaluate the usefulness of the method in detecting peripheral arterial disease and in differentiating disease severity. In a further study of 11 prospective amputees, CPP measurements were taken to determine the usefulness in evaluating amputees. A significant decrease in CPP from the chest to the dorsum of the foot was seen in limbs with arte-

rial disease, where the disease was evidenced by intermittent claudication, rest pain, and/or gangrene.

Results—The results indicate that the technique can successfully identify the presence of peripheral vascular disease, distinguish among different levels of severity, and aid in determining the optimal level of amputation consistent with wound healing, as well as assisting in following the patient's course of recovery after reconstructive vascular surgery.

Clinical and Laboratory Study of Amputation Surgery and Rehabilitation

Ernest M. Burgess, M.D.

University of Washington, Seattle, WA 98195

Sponsor: VA Rehabilitation Research and Development Service

Purpose—During the past year, the Seattle foot has become commercially available. Approximately 9,000 feet are now being worn by veteran and other amputees around the world. The design has been and has continued to be im-

proved. The research and evaluation provided by the VA Rehabilitation Research and Development Service is responsible for the development and technology transfer that has stimulated extensive additional research into pros-

thetic feet by both the industry and by other prosthetic research sources. This activity translated through technology transfer is directly reflected in improved quality of life for lower limb amputees throughout the world.

Progress—The Prosthetic Research Service is continuing active related development of additional lower limb components. A monolithic, gravity energy storing ankle is now in the process of clinical, bench and gait laboratory evaluation. The ankle provides controlled and programmed rotation, inversion, eversion and modestly enhances flexion/extension for the Seattle foot when the two units are used together. Force/motion vectors are provided by design and materials and not through conventional mechanisms.

The shank assembly intrinsic incorporated alignment device and cosmetic foam and cover are being developed to complete the VA/Seattle Below-Knee Prosthesis. At the rate of present development and evaluation we plan to have the total prosthesis available for national field testing before the end of the current (1987) fiscal year.

Socket Research. Our facility is actively engaged in automated fabrication of below-knee prosthetic sockets. We have a working agreement with the University College London, Roehampton Bioengineering Unit. Below-knee plaster male residual limb molds are digitized magnetically. These numerical data are forwarded

by satellite (Easylink) to our London collaborators where they are transferred to milling and socket forming equipment. Completed sockets are then returned to us. They can be fitted to the limb and aligned exactly as they were received from London. The fit is compliant, comfortable and the wearer can run an average of 5 miles per day 4 to 5 days per week.

We are continuing to investigate a variety of types of shape sensing including ultrasound under pressure which will allow some definition of durometer or stiffness of the tissues as well as the physical shape. The present magnetic shape sensing we use can be combined with a transducer to also measure firmness of the underlying structures, i.e. directly from the residual limb. CAD/CAM automated fabrication systems are being studied both in this country, Canada, and a number of other centers throughout the world. We are in communication with these various investigators.

Limb Viability studies continue through recent extension of funding of the micro-wound biological structure investigation and TCPO₂ evaluation of the circulatory status of residual limbs under pressure. This latter information should be useful to us in the CAD/CAM project. Forthcoming scientific publications and/or monographs will describe the progress made in this essentially basic evaluation of the healing capacity of the skin *in vivo* in the presence of ischemia and related pathological states necessitating limb ablation.

B. Lower Limb

2. Below-Knee

Sockets with Flexible Brims ---

A. Bennett Wilson, Jr., B.S.M.E., and Oscar Aizcorbe, M.D.

University of Virginia Medical Center, Charlottesville, VA 22908 and Veterans Administration Medical Center, Salem, VA 24153

Sponsor: VA Rehabilitation Research and Development Service

Progress—A practical and simple design for the below-knee amputee that uses an inner lining that is vacuum-formed from a thin sheet of the ionomer, Surlyn, has been tried and proved quite satisfactory. The change in stiffness between the supporting structure of the socket and the proximal border of the socket in this design is a function of the distance between the trim lines of the liner and the supporting structure on the one hand, as well as the thickness of the Surlyn.

Preliminary Results—Patient reaction to this design was very positive, and prostheses with sockets of this design are being used rather routinely even though until very recently we have

not had the opportunity to collect objective data in a systematic way.

One patient completed the evaluation protocol, which consists of monitoring the subject's heart rate and walking and standing activity under controlled and uncontrolled conditions with the best-fitting conventional prosthesis and with the experimental prosthesis. Experience with this 78-year-old, rather inactive subject demonstrated that the physiological monitoring system is practical, but for other reasons—such as the patient's general weakness and lack of motivation to increase his activity level—the improvement in comfort above that provided by a well-fitting light prosthesis did not affect his activity level.

Adjustable Below-Knee Socket ---

A. Bennett Wilson, Jr. and Oscar Aizcorbe, M.D.

University of Virginia Medical Center, Charlottesville, VA 22908 and Veterans Administration Medical Center, Salem, VA 24153

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The original purpose of this project was the development of custom-fitted sockets that have provisions for changing their volume as the stumps of new patients shrink. Such a feature has long been considered desirable, but was unattainable until the recent advent of new materials.

Progress—The original concept involved maintaining a constant cross section at the level of the patellar tendon and changing the volume progressively distally by making use of the

properties of polypropylene and Surlyn. Results of this approach were positive and led to a design of a two-piece system that provides a means of donning and doffing the prosthesis without subjecting the stump to shear forces. Experiments with several versions of the two-piece design have been very positive. A manual covering a design thought to be practical is nearly ready for design evaluation and testing by other facilities. Although the original purpose of an adjustable below-knee socket was to eliminate the need for a succession of sockets

until the new stump became stable and ready for a definitive artificial limb, it is felt that the

concept will probably be useful to a number of amputees as a definitive prosthesis.

ISNY Below-Knee Flexible Socket

Sidney Fishman, Ph.D.; Gustave Rubin, M.D.; Norman Berger, M.S.; David Krebs, Ph.D.

New York University Postgraduate Medical School and Veterans Administration Medical Center, New York, NY 10016

Sponsor: *VA Rehabilitative Engineering Research and Development Program for Adult Applications and the Maternal and Child Health Division of the Public Health Service for Children's Applications*

Purpose—The chief project goal is the development and application of the Iceland-Sweden-New York University (ISNY) prosthetic socket system to the below-knee amputee. The ISNY socket has previously been applied very successfully to above-knee and below-elbow prostheses. The fundamental advantage of the ISNY approach is the comfort achieved by the separation of the two socket functions—tissue containment and weight-transmission—with a separate structure providing each function. This separation allows the thin ISNY socket to contain the residuum (stump) tissues and yet to retain the qualities of lightness, flexibility, coolness, and enhanced intimacy of fit and sensory feedback. The weight-transmitting frame covers only 25 to 60 percent of the residual anatomy depending on stump length, yet it is sufficiently sturdy and durable. The major purpose of the ISNY frame is to capture the important weightbearing areas of the residual limb and to transmit these forces through the prosthesis to the floor, with minimal tissue coverage. It is designed to load the pressure-tolerant patellar tendon, medial tibial flare and shaft, and the interosseus space, while relieving the sensitive tibial crest, distal anterior tibia (kick-point), and distal end of the fibula. The “three-strut” frame design, therefore, consists of: 1) a medial horizontal brim that is continuous with the patellar bar anteriorly and popliteal pad posteriorly; 2) a distal end-cup that joins the frame to the shank; and 3) three struts that arise from the end-cup to support the horizontal brim. The two anterior struts run vertically just medial and lateral to the tibial crest, whereas the third strut runs vertically or posterolaterally along a diagonal path.

Progress—Design modifications have been accomplished to permit accommodation of the three major types of suspension: 1) the conventional leather cuff suspension is placed in the usual location relative to the patient's anatomy with the medial portion attached to the rigid frame and the lateral portion to the polyethylene socket. 2) In the supracondylar suspension, the areas below the proximal frame extensions have been left open and the usual wedge suspensions utilized. 3) In the corset suspension, the lateral aspect of the frame extends circumferentially to surround the entire residuum to provide an attachment point for the lateral upright and to enhance the structural stability at the points of side joint attachment, because these have only abbreviated distal extensions below mid-patella level.

The most important aspects of the tissue-containing polyethylene (PE) socket are thinness and flexibility, so that the socket-wall deflection reduces impact loading on the residual limb during stance phase. Studies indicate that the optimal thickness for the PE socket is approximately 0.030 to 0.060 inches. Comfortable juxtaposition of the weight-supporting rigid frame and the residuum is achieved by utilizing 5-mm Pelite cushion padding.

By the end of May 1986, a total of 27 patients had been fitted with BK ISNY prostheses. In this group, 16 prostheses utilized cuff suspension, 7 supracondylar suspension, and 4 corset suspension.

Patient reactions have been uniformly positive, with all but 3 of the 27 subjects preferring to wear the ISNY BK. Comments indicated that the socket is lighter and substantially more comfortable. Patients frequently said, “The prosthesis feels more like a part of me.”

Analysis of Below-Knee Suspension Systems: Effect on Gait

Frank L. Golbranson, M.D.; Roy W. Wirta, BSME; Eric J. Kuncir, MSBE

Veterans Administration Medical Center, San Diego, CA 92161

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this study was to determine criteria for the prescription of suspensions of below-knee prostheses. The study examines the relationships between physical characteristics of an amputee and locomotion performances when using different suspensions. Several different suspensions under investigation were: 1) supercondylar suprapatellar; 2) supracondylar; 3) PTB with cuff; 4) PTB with waistband; 5) PTB with figure-eight; 6) rubber sleeve; and 7) articulated supracondylar wedge.

Progress—The testing of 20 adult, unilateral, below-knee amputees was completed. A broad variety of analytical methods were developed to discriminate effects of different suspensions and to differentiate between subjects. Included in these methods were harmonic analyses of wave forms of the horizontal and vertical accelerations of the body and tachometer wave-form deviations of knee flexion-extension, and the calculation of mechanical work and efficiency.

Numerous variables and combinations of variables were found to distinguish differences in locomotion performances between suspensions and among subjects. Variables that provided the stronger indications of quality of gait as relating to suspensions and to stump length and shape included: a) prosthetic side knee flexion-extension wave-form deviations; b) the amount of axial movement of the stump with respect to the socket; c) harmonic ratios of the horizontal and vertical acceleration and the tachometer wave forms; and d) a quotient derived from the 5th, 6th, 7th, and 8th harmonics of the horizontal acceleration of the body.

A paper entitled "Effect of Velocity and F/L Ratio on External Work and Gait Movement Wave Forms—Preliminary" was submitted for publication. This paper, delineating locomotor performance of normal adults, presents the results of a study done to provide a biomechanical basis for analytical procedures used in the suspension study.

Computer-Aided Analysis of Below-Knee Socket Pressure

Dudley S. Childress, Ph.D. and Deborah S. Schnur, M.S.

Northwestern University, Chicago, IL 60611

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This is an ongoing project to determine if finite element analysis can be used to predict pressures at the socket-limb interface of patellar-tendon-bearing (PTB) prostheses under static loading. Three-dimensional finite element models are being developed for each of three subjects, based on CT scans. To verify the models, normal pressures at seven locations along the socket-limb interface will be measured experimentally for each subject. The effects of socket-liner stiffness, prosthesis alignment, and socket-casting techniques on the interface pressures will be examined.

Progress—A linear, elastic finite-element model for the first subject has been completed. The bone and soft tissue of the residual limb are represented by 3-D brick elements; the socket liner is simulated by boundary elements, which behave like linear springs; and the socket is assumed to be rigid. The soft tissue was assigned a uniform stiffness. A force of half body weight was applied to the proximal femur in the distal direction, and the stresses normal to the surface of the limb were calculated. The normal stresses fell within the range expected from the experimental measurements of previous investigators. The areas of highest stress,

the patellar tendon bar and the distal end of the limb, were less than 1.0×10^5 Pa. A parametric study was conducted by varying the stiffnesses of the liner and soft tissue. Increasing the liner stiffness produced the same effect as decreasing the tissue stiffness. The normal stresses increased significantly at most bony areas, such as the anterior tibia and the tibial condyles, but decreased slightly at the patellar tendon bar. These results suggest that the relative stiffness between the liner and the soft tissue is important. The clinical significance is that the socket liner could be selected to complement the condition of an amputee's soft tissue.

Preliminary Results—Much of the work for the experimental phase of the project was devoted to testing and selecting a pressure transducer. The testing consisted of applying known pressures through liner material to a transducer flush mounted in a flat plate. A strain gauge, metal diaphragm transducer was chosen for its high linearity and reproducibility, and low hysteresis. Some preliminary pressure measurements have been made with the transducer in-

stalled at the distal end of the first subject's socket. The subject used a Pelite liner, and his prosthesis was aligned so that the pylon was vertical. The forces at the distal end of the prosthesis were measured by a force plate. During the testing session, the normal pressure indicated by the transducer increased from 1.0×10^4 Pa in the morning to 6.5×10^4 Pa in the afternoon. This trend agrees with the clinical observation that the residual limb shrinks over the course of a day, which would cause it to sink down into the socket. The final pressure measurement correlated well with prediction of the finite-element model.

Future Plans—Future efforts will be directed toward collecting additional experimental pressure data and toward enhancing the finite-element models. Nonlinear material properties and large displacement capability will be added to the models if necessary to obtain agreement with the experimental data. The soft tissue stiffness at various points on each subject's residual limb will be measured in order to refine the material properties of the models.

Optimum Prosthetic Foot Characteristics for the Dysvascular Below-Knee Amputee

H.M. Sterling, M.D.; J. Perry, M.D.; J. Gronley, M.S., P.T.; L. Torburn, M.S., P.T.; V. Patmont, M.S., P.T.; L. Garrison, M.S., P.T.; R. Bechtel, M.S., P.T.

Veterans Administration Medical Center, Loma Linda, CA 92357; University of Southern California, Los Angeles; and Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The characteristics of the prosthetic foot presently prescribed for the dysvascular below-knee amputee are based on parameters developed for the young traumatic amputee and, therefore, are not directed toward minimizing energy expenditure while maximizing ambulatory function. Current guidelines for component selection are based on patient weight only. Waters and Perry have shown that the elderly dysvascular amputee walks with a sufficiently different gait pattern to demand higher energy. The dysvascular population has a lower energy reserve than other amputee

populations. Thus, they require a prosthesis that allows for the most efficient pattern of walking possible. Improving the gait pattern and decreasing physical demand will result in minimizing energy requirements while maximizing ambulatory function for the dysvascular amputee. The purpose of this study was to determine if below-knee amputee gait can be optimized by adjusting the heel firmness of the SACH prosthetic foot.

Progress—Ten dysvascular, and one elderly (67 yrs) traumatic, below-knee amputees were

tested in the Pathokinesiology Laboratory. Each subject was tested with a soft, medium, and firm-density cushion in the SACH foot. Intramuscular EMG of the lower gluteus maximus biceps femoris (long head), vastus intermedius, and vastus lateralis were recorded simultaneously with hip, knee, and ankle motion and stride analysis. Force measurements to calculate joint torques during gait were also recorded with each of the three density heels.

There were no statistically significant differences between the three heel types for EMG activity, joint motion, joint torques, or stride characteristics at the 95 percent confidence level. But, there were significant differences in these parameters compared to normal gait.

Results—The average velocity was 55.8 m/min (sd 9.4), which is 64 percent of normal. Stance comprised 64 percent of the gait cycle (sd 4.2) for the amputated limb and 67 percent (sd 4.4) for the sound limb. All three density heels resulted in prolonged heel-only contact and decreased single limb support time on the amputated side compared to normal. Although there were no significant differences between heel types, the firm-density heel cushion had a foot-floor contact pattern of slightly longer heel-only time than the medium or soft heel.

The torque measurements revealed loading response torques of slightly greater plantarflexion, and decreased knee and hip flexion torque compared to normal. Plantarflexion torque was prolonged until the end of loading response. The knee torque remained an extensor torque throughout stance phase with very minimal rate of change. The firm-density heel demonstrated a trend toward greater plantarflexion and knee flexion torque than the soft heel. The motion at the hip, knee, and ankle in loading response was much less than normally seen in gait. The compression of the heel cushion in loading created only 5 degrees of plantarflexion motion at the ankle; this was accompanied by a 3-degree increase in knee flexion and a hip posture of 20-degree flexion. From midstance to

terminal swing, knee motion was similar to that seen in normals. However, the hip reached peak flexion in mid- to terminal swing and began extending in terminal swing, just prior to initial contact. The prosthetic foot dorsiflexed to 8 degrees following heel off (i.e., forefoot motion) and returned to neutral at toe off, as expected from the SACH foot. The firm-density heel resulted in less plantarflexion and greater knee flexion than the soft or medium heels.

The EMG record showed the same phasing for each heel type for each muscle tested. Activity of all four muscles was prolonged during stance. The lower gluteus maximus was active from 0 percent (initial contact) to 22 percent of the gait cycle (end of heel-only contact in midstance), and the vastus lateralis and vastus intermedius from 0 to 36 percent (terminal stance). The long head of the biceps femoris was active from 0 to 55 percent of the gait cycle (preswing). In swing, the vastus lateralis, vastus intermedius, and long head of the biceps femoris demonstrated appropriate timing; the lower gluteus maximus activity was premature. EMG intensity was the same for all heel types for the gluteus maximus, biceps femoris, and vastus intermedius. During loading, the vastus lateralis had slightly greater EMG activity response with the firm heel than with the medium or soft heel.

The soft, medium, and firm-density heel on the SACH prosthetic foot demonstrated no significant differences between heel types in stride characteristics, joint torque, joint motion, or EMG. There were significant differences in these parameters compared to normal gait. In addition, the firm-density heel tended to create a slightly greater physical demand compared to the soft or medium-density heel as indicated by joint torques and EMG measurements. The lack of differences in gait using the three density heels commercially available suggests that further developments in prosthetic design should concentrate on ankle function in response to loads created during walking.

B. Lower Limb

3. Above-Knee

Geriatric Prosthetics: Design and Development of an Improved Above-Knee Socket _____

Hans R. Lehneis, Ph.D. and Gustav Rubin, M.D.

Rusk Institute of Rehabilitation Medicine, NYUMC, New York, NY 10016 and Veterans Administration Regional Office, New York, NY 10001

Sponsor: VA Rehabilitation Research and Development Service

Purpose —The purpose of this project is to investigate prosthetic socket design to determine an optimum design with respect to comfort and performance for geriatric above-knee amputees. Anatomical, physiological, and biomechanical characteristics of geriatric above-knee amputees are being studied to develop a set of design criteria for geriatric above-knee sockets. Factors such as residual limb circulation; muscle strength, tone, and size; tissue compressibility and compliance; skin elasticity; limb spatial orientation; and sensation are being measured and a database compiled for use in determining the requisite socket design criteria.

Progress —During the past reporting period, physiological data have been collected on 13 amputees and 6 control subjects. A tissue compressibility and compliance measurement system has been developed utilizing a low-temperature, thermoforming plastic thigh band with apertures through which a probe is inserted. The thigh band is molded around the subject's thigh at the perineal level and represents the relaxed shape of the residual limb. By applying a probe at a constant force through apertures evenly spaced around the circumference, a socket cross-sectional shape is generated from measurements of the depth of travel of the probe. This gives a measure of the compressibility and compliance of the underlying residual limb tissues.

From these data, a casting brim is fabricated, and a mold of the subject's residual limb is made using standard prosthetic techniques.

Within minimal to no modification of this mold, a socket is fabricated, and the resulting prosthetic fit is evaluated. A prosthesis incorporating this new socket is then fabricated. The static and dynamic performance of this experimental prosthesis is then evaluated and compared with the subject's previous prosthesis. Three experimental sockets have been fabricated to date.

An alternative method of determining socket shape utilizing a pneumatic system has been tried on several subjects. This method applies a constant pressure around the perineal circumference. It results in a nearly circular cross-section and thus may not provide adequate rotational control. At the present time both socket designs are under evaluation.

Future Plans —Work on this project will continue with collection of anatomical and physiological data from 96 subjects. Twenty-four of the test subjects are to be geriatric above-knee amputees, 24 are to be nongeriatric above-knee amputees, and 48 control subjects are to be nonamputees with approximately the same chronological age distribution as the amputee test subjects. These data will be compiled and stored in a computerized database for statistical analysis. Sockets and prostheses for 12 subjects will be fabricated using the criteria developed from these studies. All prosthetic parameters other than the shape of the sockets will be kept identical to the subjects' previous prostheses for purposes of comparison and evaluation. Prosthetic socket fit, comfort, and static and dynam-

ic performance will be evaluated and compared to the subjects' previous prostheses by a pros-

thetist, a physical therapist, and the subjects themselves.

Rigid Knee Prosthesis

Edward C. Grahn and David J. Dvorak
Northwestern University, Chicago, IL 60611

Sponsor: *National Institute of Handicapped Research*

Purpose—The use of a rigid-knee gait by an above-knee amputee provides exceptional safety, stability, and proprioceptive feedback. A prosthesis especially designed for this type of gait may prove to be effective for sporting activities and for geriatric amputees whose inadequate swing phase knee flexion actually inhibits ground clearance.

Progress—In order to restore the ground clearance function normally provided by sufficient knee flexion, a dorsiflexing ankle mechanism can be used, thereby reducing energy expenditure and gait deviations. A simple design was developed, having a single-axis joint centered through the usual ankle joint location, providing plantarflexion relative to the midstance position, and rotating to a dorsiflexed position during the swing phase. Two methods are being investigated for activating the dorsiflexion stop during the stance phase: the application of body weight and the presence of shank torsion. Rigid-knee prostheses of both designs are being prepared for testing over a variety of walking surfaces.

Preliminary Results—A geometric investigation of ground clearance has been completed. This study involved 2-D and 3-D models of conventional AK prostheses as well as dorsiflexion requirements for a rigid-knee prosthesis. In order to more closely examine ground clearance and the means by which it may be achieved, a three-dimensional model of clearance was de-

veloped. In this model, the shape of the rim of a shoe was described by a series of points, representing both the transverse and sagittal profiles of the shoe. This 3-D model allowed an examination of the effects of initial foot rotation (with respect to ankle axis), ankle axes that are skewed in the coronal and transverse planes, swing phase rotation about the long axis of the limb, and circumduction.

Although the major effects of ground clearance were evidenced by the 2-D models, it was discovered that the "roundedness" of the toe and heel sections in the transverse plane do contribute slightly to ground clearance when used with a skewed-single-axis dorsiflexing ankle. That this design feature does not inhibit ground clearance is important from the standpoint that it allows one the flexibility to choose ankle orientation that would achieve the best stance phase response.

The models indicate that a mechanism providing about 4 degrees of dorsiflexion relative to the unloaded midstance position of a normally aligned foot provides the most clearance in rigid-knee walking. Because the alignment of the VA SEATTLE Foot places the foot in relative plantarflexion in order to preload the energy-storing keel, the dorsiflexing device for such a foot should provide an additional 10 to 15 degrees of dorsiflexion relative to the unloaded foot. This combination of foot and dorsiflexion mechanism would provide energy storage without increasing the possibility of ground clearance problems.

Myoelectrically Controlled Above-Knee Prosthesis

Gordon D. Moskowitz, Ph.D; Ronald J. Triolo, Ph.D; Howard Hillstrom, M.S.

Drexel University, Philadelphia, PA 19104 and Veterans Administration Medical Center, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The need exists for active volitionally controlled above-knee (AK) prostheses that are more easily controlled by the amputee. Currently, control of lower limb prostheses has been largely limited to preprogrammed, passive devices that are awkward and difficult to control. The most popular means of passive control is the use of fluid damping mechanisms at the knee joint. Active volitional control of a prosthesis permits continuous adjustment to changing gait conditions, decreasing metabolic energy usage and enhancing the ability to respond to extraordinary events, such as stumbling.

A myoelectrically controlled AK prosthesis is under development at this laboratory that provides greater conscious and subconscious active control in gait and nongait activities. This prototype prosthesis has three principal operating subsystems: a myoelectric signal processor, a controller, and a hydraulic/pneumatic (H/P) actuator.

The myoelectric signal processing that we employ includes spatial pattern recognition and time-series methods. At present, it is believed that the patterns of EMG used for control are nonstationary and therefore may compromise controller performance and/or require more energy, effort, and concentration on the part of the user over time. The requirements for relevant specifications for adaptive spatial pattern recognition are being quantified.

Progress—Progress was made in the following areas:

a) Successful application of spatial pattern recognition methods in discrimination between intended knee and hip activity among normal and above-knee amputee subjects.

b) Development of a pneumatically powered AK test actuator with the following characteristics: 1) the ability to produce torques actively and in opposition to externally applied torques; 2) the ability to recover energy as op-

posed to conventional actuators, which act only as energy dissipators.

c) Successful integration of the actively powered test actuator with the spatial pattern recognition control algorithm.

d) Demonstration of an alternative control strategy based on time series features of the EMG signal.

e) Development of an optimal electrode placement technique for spatial pattern recognition that provides a quantitative means for locating electrodes.

Preliminary Results—Results thus far include the following:

a) Development and verification of a complete and robust multichannel time series myoprocessor that performs both limb function classification and muscle force estimation. The system consists of an optimal myoprocessor applied to the prewhitened residual sequences of each AR filter employed in the limb function classifier and offers the following advantages: 1) Modeling the EMG as an autoregressive process incorporates temporal information that reduces the number of electrodes required for the reliable detection of the direction of intended limb motion. 2) Incorporating spatially distributed information in the parallel filtering classifier by modeling multiple channels of EMG activity as a vector process with multidimensional AR filters increases the peak performance of the detection system, reduces classifier sensitivity to exertion level, and expands the operating range to include clinically useful levels of contraction. 3) Prewhitening the EMG with the AR filters extends and completes the optimal myoprocessor to include multiple channels of serially correlated data. It allows both muscle force estimation and limb function detection to be accomplished simultaneously by a single, hybrid system with great computational economy. The multichannel time-series myoprocessor (MTSM)

represents the first time-series-based system to provide both binary decisions and a proportional control signal, and therefore specifies a complete and self-consistent intent recognition system. In both simulations and tests with real EMG data from sites intermediate to the vastus lateralis and biceps femoris, identifying the AR models at lower levels of contraction was found to improve total system performance. Classifier performance and range of operation increased with the number of channels included in the processor. Contrary to the simulations and expectations based on the work of Hogan, neither prewhitening nor multichannel processing was observed to improve the fidelity of the force estimates obtained from electrodes located between muscle groups.

b) Development of Gaussian Bayesian reference models to EMG-based intent recognition

and real time control of artificial lower limbs was accomplished. SNR and percent CC were obtained and proved superior to short-term models. Minute and hour scale stationarity was observed in parameters that were nonstationary in short-term models.

c) Simulation, design, and fabrication of a second actuator prototype has been completed. This new actuator is a hybrid hydraulic/pneumatic that is currently being assembled.

Future Plans—Next year the following efforts are planned:

a) Complete construction of pneumatic/hydraulic prototype.

b) Complete design of Robust Pattern Classifier.

c) Begin development of time-series-based prosthesis controller in real-time.

Transparent Flexible Sockets for Above-Knee Prostheses

M. Fahrer; M. Van Lith; A. Donnelly; M. Overton; V. Angliss

Commonwealth Department of Veterans' Affairs, Central Development Unit, Royal Talbot Rehabilitation Hospital, Kew 3101 Australia

Sponsor: Department of Veterans' Affairs

Purpose—This project compared the two major types of transparent flexible AK sockets for introduction on the D.V.A. Free Limb Scheme. The study concentrated on durability and reliability.

Progress—Twenty-two patients were successfully fitted with transparent flexible sockets. It was found that a modified IPOS type is more suitable for the Free Limb Scheme because: 1) The standard quadrilateral brim is prone to

breaking at the corners, especially the posterolateral one. 2) The rounded IPOS brim is more resistant. 3) "Surlyn" is easily deformed by "creeping" to the point of losing suction within weeks of wearing. 4) Polyethylene sockets seem to be much less affected by creeping. 5) The semi-flexible IPOS frame seems more resilient to axial rotating torque forces. 6) The IPOS valve provides a simple and reliable device for fixing the socket to the frame.

A Telemetric Data Acquisition and Processing System for Biofeedback Training and as a Diagnostic for Human Movement Training

Woodie Flowers, Ph.D.

Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: National Institute of Handicapped Research

Purpose—This work is a continuation of a past effort that began with the specific aim of improving gait training of AK amputees. The

result of previous work was a self-contained portable force and movement measurement system that provided biofeedback of gait pa-

rameters. Two transducers, prosthesis shank axial load and hip angle, were developed and integrated into the MIT STRIDER system. The STRIDER has been used and evaluated by the physical therapy staff at the Massachusetts General Hospital (MGH), and their reactions were enthusiastic.

A second version of the system, the MIT TRAINER, has been designed and developed. Measurements from the same transducers are input to a computer via a telemetry data transmission system. The personal computer increases the flexibility of the system in many ways. The therapist can easily alter threshold values and choose among various forms of bio-feedback both visual and audio. Also, data analysis can be accomplished with relative ease. Another benefit of this system is the reduction of the size and weight of the devices worn.

Progress—During the past year, a comprehensive software package was developed for this system. It allows the design of images that are used to display feedback for a person undergoing rehabilitation. After calibration, these images move on the CRT screen as a representation of the current sensor values. During a training session, the system simultaneously records the input data and displays the dynamic images. Graphs of the data are available when the session is complete. Packaging of the circuitry that interfaces the STRIDER transducers with the new system has been completed. This includes fabrication of printed circuit boards and cases to house them.

Currently, the system is complete, and plans for experiments are under way. Goals of these experiments are to establish the effectiveness of this system as a learning aid.

C. Upper Limb

1. General

Improvement of Body-Powered Upper Limb Prostheses

Maurice LeBlanc, MSME, CP

Rehabilitation Engineering Center, Children's Hospital at Stanford, Palo Alto, CA 94304

Sponsor: National Institute of Handicapped Research

Purpose—The overall goal is to improve the acceptance and use of standard body-powered upper limb prostheses by arm amputees in the United States. The specific objective of this project is to improve conventional arm prostheses by means of a hydraulic force transmission system.

Estimates of population in the U.S. place the number of upper limb amputees at 100,000, with 50 percent actually wearing prostheses. Of the 50,000 wearers, an estimated 90 percent use body-powered and 10 percent externally powered arm prostheses.

Standard, body-powered upper limb pros-

theses have not changed significantly since developments in the 1950s spurred by World War II. They still employ aircraft technology, using shoulder harnesses and steel cables for operation. Many arm amputees are now purchasing externally powered arm prostheses because they look more modern and "bionic," when, in fact, a body-powered type may be more appropriate functionally. Amputees may be going to the more expensive externally powered type to get comfort and appearance they should be getting from the body-powered type.

Progress—Progress to date has been made in

the following areas:

1) This project has confirmed strongly that current body-powered upper limb prostheses need improvement and that the force transmission system is critical in doing so.

2) The replacement of the cable control system by a hydraulic control system is feasible and offers possibilities for more efficient use of body power.

3) The use of a hydraulic control system unlocks potential benefits in function, comfort, and appearance not feasible with the cable control system.

4) There are problems with the use of hydraulics that must be solved to be acceptable. These problems are not easy ones, or changes would have been made over the past 35 years. Still, it appears that they are solvable and that this line of work should continue.

5) The benefits of bringing the potential of this project to successful implementation include: a) cost savings with appropriate prescription and purchase of body-powered arm pros-

theses for some amputees; b) psychosocial improvement to current users from better function, comfort, and appearance; and c) conversion of some nonwearers into wearers, with resultant increase in body image, bilateral function, and vocational achievement.

Future Plans—Effort will be directed toward below-elbow prostheses because they are the most common and fundamental. Hydraulic control systems will be designed, built, and tested in use with amputees and compared with conventional cable control prostheses.

In some ways, the below-elbow prosthesis is the most difficult level to implement hydraulics because amputees need improvement less than at higher levels and because there is not as much space in the forearm for packaging the components. However, if the hydraulic control system can be implemented successfully at the below-elbow level, the presumption is that benefits will be amplified at higher levels of amputation.

Myoelectric Prosthetic System

Dudley S. Childress, Ph.D. and John S. Stryzik
Northwestern University, Chicago, IL 60611

Sponsor: National Institute of Handicapped Research

Purpose—The objective of this project is to develop modular electronic components for the control of electric powered prostheses. These components are: 1) An active encapsulated electrode that contains the preamplifier and is to be used with any of the below-described processors for controlling electric powered prosthetics components. 2) A single-site signal processor with a single output for controlling a powered device such as the Michigan child's hook or the

Hosmer Dorrance Prehension Actuator. 3) A single-site signal processor to control any hand, hook, or elbow in two directions.

Progress—A manufacturer has begun the production of Items 1 and 2. The development phase of Item 3 has been completed, but it has not been clinically evaluated nor presented to a manufacturer.

Extended-Limb Prostheses

Edward C. Grahn and Hal Krick, CP
Northwestern University, Chicago, IL 60611

Sponsor: National Institute of Handicapped Research

Purpose—The objective of this project is to determine if under some conditions, simple exten-

sions of the limbs of persons with high level upper limb amputations can be more effective

functional tools than conventional types of prostheses. One concept is a prosthetic socket with a device attached to its immediate distal end that will enable a person with an above-elbow amputation to write more easily. This would utilize a writing device that is now commercially available but that is intended for a hand orthosis. It comes with three interchangeable tips that allow the user to choose a pencil, a pen, or an eraser.

Progress—The first subject for a clinical evaluation of this concept was a 30-year-old man with traumatic amputations above-elbow bilaterally and hip disarticulation on the right side. He was fitted bilaterally with above-elbow prostheses; a lower limb prosthesis allowed the subject to walk quite well. The left above-elbow prosthesis consists of a 5XA hook with a Hosmer Dorrance Prehension Actuator (PA) and standard body-powered elbow. The right side consists of a 555 (lyre-shaped) hook canted medially approximately 20 degrees, a PA (outer shell only) to provide passive wrist rotation, and a standard body-powered elbow. Both PAs have the rotational resistance set low to allow the subject to achieve wrist rotation by “rolling” on the table edge. Although the subject

was able to accomplish many activities of daily living, he was unable to write legibly with these prostheses.

A prosthetic socket with a writing device attached to the distal end was fabricated for the subject's right (dominant) side. This was intended to replace the standard prosthesis only when the subject wanted to write. The subject was able to write legibly. In fact, he stated that it resembled his handwriting prior to the accident that caused the amputations. He was readily able to change tips to choose between pen and pencil. He found the device useful and wanted to keep this prosthesis for use at home.

Future Plans—The next step in development is to incorporate this device into a standard prosthesis so that the user does not require someone to change the entire prosthesis whenever he wishes to write. This will require a simple disconnect mechanism that can be operated by the person wearing the prosthesis to permit easy removal of that part of the prosthesis distal to the writing device. It must also contain electrical contacts when electrical components are distal to this point and electrodes or switches and/or battery cables are proximal.

An Electric Artificial Limb for Children Without Limbs

Craig W. Heckathorne, MSEE; Dudley S. Childress, Ph.D.; Edward C. Grahn, BSME; Hal Krick, CP; John S. Strysik
Northwestern University, Chicago, IL 60611

Sponsor: *National Institute of Handicapped Research*

Purpose—The objective is to develop an artificial arm that can be used by children born without arms. To provide effective control of the arm, we will be implementing a force-actuated position-servo controller based on Simpson's concept of extended physiological proprioception (EPP).

Progress—A prototype EPP-controller has been developed and implemented on the NU/Michigan Arm. This arm is a child-size prosthesis (ages 3-6 yrs) developed by our laboratory for

the Area Child Amputee Center in Grand Rapids, Michigan. Four of these arms have been constructed for the ACAC and are presently controlled with switches. We are refining the electronics of the EPP-controller in preparation for an initial clinical fitting. An upscaled version of the NU/Michigan Arm (Size 2) has recently been completed on contract the ACAC. This arm is sized for children ages 7-13 years. If warranted by our field evaluations with the EPP-controller on the Size 1 arm, we will evaluate the controller with the Size 2 arm.

Design of Prehension Systems for Upper Limb Amputees

Craig W. Heckathorne, MSEE; Dudley S. Childress, Ph.D.; Edward C. Grahn, BSME; Hal Krick, CP
Northwestern University, Chicago, IL 60611

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The overall objective is to increase the variety of powered prehensile devices available to persons with upper limb amputations. Specifically, we are proposing: 1) new utilitarian prehensile fingers that are not based on the traditional hook shape; 2) a cosmetic hand with high performance characteristics; and 3) a utility hand that would serve as a compromise between utilitarian and cosmetic designs but would have advantages of both.

Progress—We are presently completing refinement of a power-base mechanism that will serve as the actuator of the prehension devices outlined above. Details of this mechanism were given in the last progress report. We also have initiated contact with an industrial design group that will be consulting on the design of the utility hand.

Position-Servo Control of Upper Limb Powered Prostheses

Craig W. Heckathorne, MSEE; Dudley S. Childress, Ph.D.; Hal Krick, CP; Lew J. Leibowitz, BSEE; John S. Strysik
Northwestern University, Chicago, IL 60611

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Experience has shown that users of powered multijoint prostheses must give considerable attention to the control of these prostheses. The effective use (i.e., with low mental loading) of more than two-powered joints in coordinated movements does not appear possible using "velocity-control" approaches (e.g., switch and myoelectric controllers).

We are proposing to implement a force-actuated position-servo controller, coupling an anatomical joint(s) and a prosthetic joint(s), as a means of achieving improved control of multijoint powered prostheses. This type of controller is based on Simpson's concept of extended physiological proprioception (EPP). Position and velocity of the prosthetic joint are controlled by the anatomical joint. And, because of the coupling between the joints, the user is constantly aware of the position and velocity of the prosthetic joint through the proprioception of the anatomic joint. The effectiveness of this control has been demonstrated empirically in Simpson's applications to gas-powered prostheses and experimentally in comparisons with velocity control of electric-powered prostheses.

Progress—We intend to evaluate the EPP-controller through field testing. Consequently, it is necessary that the force transducer have low power consumption, be relatively inexpensive, and be mechanically rugged. After rejecting strain gauge, capacitive, and pressure transducers for failure to meet one or more of these criteria, we are presently experimenting with a relatively new, commercially available thick-film force-sensitive resistive material. Although our evaluation of the material for the EPP-controller is not complete, a prototype controller has been constructed and appears to be very promising. A Hosmer NYU elbow has been modified for the prototype controller. Initial results suggest that its mechanical response is sufficiently good to exploit the advantages of an EPP-controller. We are also beginning to develop the prosthesis' support and harnessing system for the field evaluation. The initial fitting will have only the electric elbow controlled by the EPP-controller, with the terminal device under myoelectric control.

Cosmetic Covers for Upper Extremity Prostheses (Male/Female)

Robert A. Erb, Ph.D. and Lawrence Cerullo

Franklin Research Center, Philadelphia, PA 19103 and Veterans Administration Medical Center, Philadelphia, PA 19102

Sponsor: VA Rehabilitation Research and Development Service

Purpose—A project objective is to develop realistic and durable cosmetic covers for hand and arm prostheses for men and women. Advanced materials and procedures are being used to achieve this objective. A concept being investigated is to use, where possible, a subject's remaining hand for mirror-image replication to produce a matching cosmetic cover.

Preliminary Results—Activities and results to date include the following:

1) Studies were made of advanced materials for primary molding (e.g., two-component vinyl silicones with an inline mixer); for casting (wax compositions); for secondary molding (castable polyurethanes that do not inhibit the cure of silicones); and for the final cover (clear vinyl silicones).

2) Means were developed for making an essentially seamless split mold of flexible material. The developed device, termed a "zip strip," is a preformed, flexible strip with hemispherical keys on a separator-treated face. The zip strip is fabricated in straight and curved configurations in silicone rubber for primary molding and in polyurethane rubber for secondary

molding.

3) A 3-D reversing pantograph was fabricated and demonstrated with hands and forearms.

4) Techniques were developed for making skin-textured forms with fingers and wax-shell overlays cast in silicone-rubber primary molds.

5) A concept was made for a universal-sized internal skeleton for cosmetic covers. Active-hand prototypes were made using pivoted, square telescoping tubing with polyester film tendons for flexion and torsion springs at each joint for extension. The single-control prototypes (thumb plus two moving fingers) show excellent dexterity and conformability in grasping objects of various sizes and shapes.

6) A color triangle series is being designed for quantitative pigmentation for intrinsic coloration.

7) Experimental efforts have begun on development of flexible, split secondary (final) molds and on multilayer fabrication of cosmetic covers using intrinsic coloration.

Future Plans—Plans include fabrication of appliances for wearer studies and technology transfer to those in the field.

Prosthetic Terminal Device for Playing the Piano

Daniel J. Koester, B.S.; Simon P. Levine, Ph.D.; Warren S. Jocz, B.S.; Khan D. Bui, B.S.

Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center, Ann Arbor, MI 48109-0032

Sponsor: Rehabilitation Engineering Division, Department of Physical Medicine and Rehabilitation, University of Michigan

Purpose—This project involves the development of a device to enable a person fitted with a below-elbow prosthesis to play the piano. Our efforts have been geared for a particular client, but the design could have general application for other below-elbow amputees.

The client for whom the device has been developed is a 10-year-old girl who has both natural ability and a strong desire to play music. She has a congenital deficiency of the

left arm, a disability equivalent to a short below-elbow amputation.

Progress—We continue to work closely with this client, her piano instructor, family, and Rehabilitation Engineering staff. Early in the project, a prototype was constructed with two fingers which could be adjusted and then fixed in position. The client was successful in using this device to develop a large repertoire and

even to perform recitals with her peers.

Preliminary Results—Recently, an interim device that enables finger spread via a foot control and cable has been developed. A design for

a more sophisticated device with variable finger-spread and wrist rotation has also been developed, but it now seems unlikely that the more complex system will need to be implemented at this time.

Quantification for the Functional Capability of Upper Extremity Amputees

Neville Hogan, Ph.D.

Harvard University and Massachusetts Institute of Technology, Cambridge, MA 02138

Sponsor: *National Institute of Handicapped Research*

Purpose—This project will develop and apply a technique for quantification and measurement of the upper extremity functional capability of able-bodied and disabled persons. The technique being developed has a sound practical and theoretical basis. Performance is measured on specific tasks that represent the functional role an upper extremity prosthesis can realistically be expected to play. Competent mathematical models of normal human control strategies are then used to produce a single meaningful number derived from accessible measurements (such as myoelectric activity, speed, range of motion, etc.) and provide the essential link between measured performance and inferred functional capability. Previous progress reports and several publications have described the mathematical techniques used to model human upper extremity motor coordination. Efforts in the past year have focused on the refinement of the experimental tasks.

Progress—A unique approach to the assessment of the causes underlying the functional disability of an amputee using a prosthesis has been developed. The disability of an amputee using a prosthesis could be attributed to many causes: sensory loss, damage to the amputee's nervous system, poor mechanical performance of the prosthesis, and poor interfacing between amputee and prosthesis are among the prominent candidates. In this project, we will attempt to determine how much of the observed functional deficiency can be attributed to the dynamic performance of the prosthesis itself. To do this we have developed an arm brace (similar to an orthosis) that allows us to add

passive dynamic loading to the arm of an able-bodied subject. With this device we can approximate in the able-bodied subject the relation between muscular activity and arm motion that an amputee using a myoelectrically controlled prosthesis has to deal with. For example, the maximum speed of intact elbow motion can be restricted to that of the prosthesis.

To quantify performance precisely, we have investigated some simple but representative contact tasks an amputee may need to perform (e.g., opening a drawer or opening a door). These tasks can be difficult with current artificial limbs because the tasks require the artificial joint to accommodate a nontrivial kinematic constraint. In addition, the mechanical joint (the elbow) must be coordinated with the natural joints (e.g., the shoulder). An analysis of the mechanics of crank-turning showed that there are critical points along the crank trajectory where shoulder/elbow coordination is essential; at these points, due to the geometry of the arm/forearm/crank linkage, neither joint torque alone is sufficient to drive the crank—some combination of the two is required.

Preliminary Results—To date, our investigations of crank-turning have shown distinct performance differences between able-bodied and amputee subjects, but they also showed that the subject's ability to recruit other joint motions, such as bending the knees and "floating" the scapula, could compensate surprisingly well for functional limitations of the elbow joint. We could have restricted body motions by seating the subjects and strapping the torso to the chair, but then the test would little resemble

the conditions under which activities of daily living are performed.

We therefore modified the crank-turning task to better resemble a more difficult but reasonably common activity: wiping a curved surface, moving a hand along it in a controlled way while exerting a normal force. This task is especially interesting if the surface is convex, because unless the direction of the hand's force on the surface changes appropriately with its position, the hand will tend to "fall off" the convex surface. The problems posed by a convex surface are simulated (in two dimensions) by a crank whose handle is cradled in a

V-shaped notch at the end of the crank arm, but not attached to it. If the notch is sufficiently shallow, this is a challenging task even for an intact subject. To vary the level of difficulty, the angle of the notch is adjustable from a broad V (70 to 80 degrees), through to full capture of the handle. In the limiting case (a fully captured handle) this task becomes kinematically equivalent to the original crank-turning task.

At present, project activities are focused on conducting experiments with amputee and able-bodied subjects.

A Microprocessor-Controlled Prosthesis with Extended Physiological Proprioception

Michael D. O'Riain, Ph.D.

Royal Ottawa Regional Rehabilitation Centre, Ottawa, Ontario K1H 8M2 Canada

Sponsor: *Royal Ottawa Hospital*

Purpose—The objective of this project is to design a new upper extremity prosthesis with extended physiological proprioception (EPP), that will have improved performance characteristics compared with already existing devices. The prototype prosthesis is designed for an above-elbow amputee. It is equipped with powered actuators for elbow flexion/extension, wrist rotation, and hand prehension. Elbow and wrist functions are controlled by shoulder flexion/extension, which is measured by a specially designed shoulder goniometer. Hand prehension, which is not a position function, is controlled by EMG signals from biceps and triceps muscles.

Progress—Unique features of the prosthesis are as described below.

Instead of a single input/output relation, as is found in standard prostheses with EPP, up to eight different input/output relationships (or linkages) can be programmed into the microprocessor memory for selection by the user. This will significantly increase the usefulness

of the prosthesis. However, the absence of a single input/output relationship may confuse some of the users. The extent of this limitation has yet to be determined experimentally.

Conventional EPP prostheses have what is termed an "unbeatable servo" feature that continuously prevents the input from exceeding the output capabilities of the system. Our prosthesis will not have such a facility. However, it will warn the user with a vibrotactile stimulus if the input is exceeding the output capabilities of the system. The user can then either back-track or wait until the output catches up with the input signal.

System dynamics are controlled by the microprocessor system. This gives users more flexibility than they would have if the system dynamics were controlled by hard-wired electronic circuitry.

Future Plans—A bench prototype has been constructed and tested. Presently, a prototype to be worn by an amputee is being constructed, and tests will be performed on it in the near future.

Implementation of Extended Physiological Proprioception for Prosthesis Control_____

William G. Winter, M.D. and Lawrence E. Carlson, D. Eng.

Department of Orthopedic Surgery, Veterans Administration Medical Center, Denver CO 80220 and Department of Mechanical Engineering, University of Colorado, Boulder CO 80309

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Extended Physiological Proprioception (EPP) is a control concept that has demonstrated certain advantages for the position control of upper limb prostheses. The goal of this project is to control a Utah Arm with EPP, fit it to an above-elbow amputee and evaluate its performance.

Progress—Previous research by this investigator developed a small transducer and the necessary electronic circuitry to control a VA elbow by EPP. The initial phase of this project focused on getting the EPP system to control the Utah Arm under laboratory conditions. Following discussions with Motion Control, Inc., manufacturers of the Utah Arm, it was decided that the best method to control the arm would be to generate a simulated myoelectric signal and utilize the arm's circuitry. Therefore, a circuit has been designed and tested which generates a synthetic EMG signal of the appropriate sign to cause the arm to move in the desired direction. The complete circuit has been packaged onto a circular circuit board which will enable it to be

contained in a small space above the elbow.

Computer simulations of the four-bar linkage which provide the final drive of the elbow were undertaken in order to design the optimum attachment point for the mechanical feedback cable. The goal is to have as linear a relationship as possible between elbow angle and cable excursion. The variables that affect the relationship are the cable attachment points on the forearm housing. The computer simulation allowed these parameters to be varied until an acceptable combination of cable excursion and linearity were achieved.

Future Plans—Final integration of the mechanical and electrical systems is nearing completion. The next phase of research will be to instrument the prosthesis for monitoring of significant variables during amputee testing. These include input cable excursion, feedback cable position and elbow angle. Also under development is the data acquisition system for an IBM PC-AT which will allow the data to be recorded by the computer for analysis.

C. Upper Limb

2. Below-Elbow

Below-Elbow Prosthetic System _____

Dudley S. Childress, Ph.D; Edward C. Grahn; John S. Stryzik
Northwestern University, Chicago, IL 60611

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of this project is to develop a below-elbow prosthetic system with prehensor (hook/hand) interchangeability and easily removable modular components. The

components consist of the prehensors: a NUVA Synergetic Prehensor and an electric hand; the signal processor circuit board; the active electrodes; a ground electrode; a battery pack; and

a wrist connector, which provides the mechanical and electrical connection between the prehensor and forearm.

Progress—A manufacturer has fabricated production prototypes of all the components except

the battery pack. Commercial availability of this system to the consumer, through a prosthetics facility, is expected in the near future. This laboratory will continue to work with the manufacturer in an advisory capacity.

Acceptability of the "Contour" Terminal Device for Below-Elbow Amputees

V. Angliss, B.App.Sc. and M. Fahrer, M.D., FRACS

Commonwealth Department of Veterans Affairs, Central Development Unit, Royal Talbot, Kew 3101 Australia

Sponsor: *Department of Veterans' Affairs*

Purpose—A trial conducted last year on 10 below-elbow amputee patients concluded that the "Contour" terminal device (T.D.) is less functional than the standard Split Hook T.D., but seems socially much more acceptable to patients and their families because of its streamlined "robot hand" appearance.

Progress—One of our patients, a male congenital amputee, has volunteered to use exclusively the new "Contour" T.D. for a period of 6 months. He reported that despite its functional shortcomings, he prefers it by far to the old "hook" for his professional activities as a solicitor, as well as at home.

The VIENNA ROTATION ARM—a Below-Elbow Prosthesis

Wolfgang Karas, Dipl. Ing.

Institute for Orthopedic Technics Research, A-1050 Vienna, Austria

Sponsor: *Special fund*

Purpose—The objectives of this project were to design and evaluate a comfortable, lightweight, and cosmetically acceptable prosthetic system for the requirements of unilateral below-elbow amputees. For these patients, their natural hand is dominant; the prosthesis is mainly utilized in a supporting role. Therefore, the advantage of using the remaining stump prosupination for operating and control of the terminal device outweighs the loss of active wrist rotation of the prosthesis. Besides, this kind of control offers a high degree of sensory feedback relative to force and position.

Progress—The terminal device has been designed to provide the "3-jaw chuck" type prehension. Rotation of the stump is transmitted into finger movement by means of a highly efficient spatial transmission. A simple gear-shifting mechanism increases by 70 percent the finger prehension force during holding phases.

In addition, this mechanism avoids reaction forces at the stump while carrying objects in the "hook or snap" type prehension.

The hand has been designed to fit into a standard cosmetic PVC glove, size 7-3/4. A small open above-elbow harness rests on the epicondyles of the humerus and is hinged at the elbow to two steel bars fixed to the hand. An inner socket fitting the stump end is connected to and operates the terminal device. The total weight of the VIENNA ROTATION ARM is about 600 g.

Final Results—In the past 3 years, 12 amputees were fitted with this arm prosthesis with very good results. Patients' stump lengths varied from 15 cm to wrist exarticulation. Some of our patients primarily fitted with myoelectric hand prosthesis were pleased especially with respect to the light weight and comfort of the open socket.

The project has been finished. Because its design is simple, the VIENNA ROTATION ARM is suitable for mass production, and man-

ufacturers are invited to contact the Institute. In the near future, a detailed paper on the VIENNA ROTATION ARM will be published.

II. Orthotics

The Role of Pressure Distribution Measurement in Diabetic Foot Care

Peter Cavanagh, Ph.D. and Lee J. Sanders, D.P.M.

Veterans Administration Medical Center, Lebanon, PA 17042

Sponsor: VA Rehabilitation Research and Development Service

Progress—Research activities to date have included the completion of Phase 1, instrumentation development, at Penn State University (PSU). Activities at PSU have included the development of a new calibration jig, configuration of new computer hardware, and the development of software for the collection, processing, averaging, and display of pressure data. Activities at the Lebanon VAMC have included the identification of 100 possible diabetic subjects for Phase 2 participation.

Phase 2, data collection and treatment, began with a comprehensive medical screening of 87 patients. Examination included a comprehensive neurological screening with testing for deep tendon reflexes; plantar response; proprioception; hot/cold discrimination; sharp/dull discrimination; and vibratory sense with quantitative assessment of vibratory perception thresholds (VPTs), using the Bio-Thesimeter. Sensibility testing for protective levels of sensation (light touch and deep pressure) was accomplished using Semmes-Weinstein monofila-

ments. Patients were then placed in risk categories based upon loss of protective levels of sensation and elevated VPTs. An orthopaedic/biomechanical examination was also performed to identify underlying structural and functional abnormalities of the lower extremities, and Harris Mat footprints were made for all patients. In addition, dermatological examination and vascular assessment with computation of ankle/arm indices were accomplished for all patients.

Preliminary Results—The records and data collected for all of these patients were then reviewed, and criteria were established for the inclusion or exclusion of patients. Criteria for inclusion will include VPTs > 20 , loss of protective levels of sensation, history of previous plantar ulceration, and structural deformity that would predispose the patient to plantar ulceration. Patients selected were then randomly assigned to two groups—enhanced care and standard care.

Biomechanics of Knee-Ankle-Foot Orthoses

S. E. Solomonidis; C. Szary; D. Gozal; J. P. Paul

University of Strathclyde, Wolfson Centre, Glasgow G4 0NW Scotland

Sponsor: Scottish Home and Health Department

Purpose—Work is still in progress on the previously reported project at the University of Strathclyde to determine the loads on knee-ankle-foot orthoses (KAFO) during patient activity (see *VA Rehabilitation R&D Progress Reports—1985*). The experiments are being carried out at the Biomechanics Laboratory of the university in association with various Glasgow-area clinicians. The purpose of the investiga-

tion is: 1) to determine and analyze the loads acting on various components of the orthosis during ambulation; and 2) to determine the load actions between the orthosis and the patient with a view to establishing realistic design criteria, the ultimate aim being the development of lighter and more comfortable orthoses.

Progress—An extensive survey of the available

literature on the subject showed that the loads applied on KAFOs to date have not been fully evaluated. Thus, at present, it is not possible to predict with any certainty the magnitude and direction of the major load actions. Therefore, it was decided to design and build a measuring system capable of analyzing loads in three dimensions. The system employs several specially built multichannel load transducers capable of measuring three forces and three moments (i.e., axial force, A/P and M/L shear, torque along the long axis on the orthosis, and A/P and M/L bending moments). The transducers are fitted to each section of the uprights—that is, proximally at the medial and lateral sides, and distally at the medial and lateral sides. Additionally, special miniature transducers measure the tension of the knee apron and other straps. When the instrumented patient/orthosis system is used in conjunction with gait analysis facilities, such as force platforms and kinematic measuring systems recording the spatial configuration of the KAFO and patient's limbs, it is

possible to determine the loads transmitted by the orthosis and the supported limb. This system has been used to acquire loading data on several categories of patients wearing various types of KAFOs (conventional or modern "cosmetic" type).

Preliminary Results—It was found that the most critical loads on a KAFO from a structural point of view are the A/P and M/L bending moments. Stress analysis on the various components of the KAFO indicated that in certain cases, the magnitude of loads recorded during the experiments can cause fatigue failures despite the apparently robust construction of these orthoses. Detailed design study has shown that generally there is an inefficient distribution of material. Several cases of KAFO failures experienced during patient activity were studied, and appropriate recommendations for design modifications were made. This study has also given us a better understanding of the biomechanics of the orthotic devices.

Technical and Clinical Evaluation of Self-Fitting Modular Orthoses (SFMOs) _____

Dejan Popovic

University of Belgrade, 11000 Beograd, Yugoslavia

Sponsor: *National Institute of Handicapped Research and Scientific Community of Serbia*

Purpose—Self-fitting modular orthoses are intended to compensate for partial or total impairments of locomotor functions. The mechanical system can be used in higher thoracic and lower cervical lesions in combination with the plastic corset to maintain the body in an upright position. Total SFMOs can be applied to middle and lower thoracic lesions with pelvic caps (if the hip control is needed), or in any combination of six independent SFMO modules (the ankle, the knee, and the hip module).

The SFMO application is indicated for partial and total paraplegics (lesions above T4) and for patients with multiple sclerosis, transversal myelitis, muscular dystrophy, and similar impairments.

Currently, investigators are combining SFMOs with the Hybrid Assistive System (HAS), a new method of gait restoration being

developed to provide hybrid orthoses for motor restoration.

Progress—Prefabricated elements are used in the SFMO technology. Production methods permit the use of the device immediately after the onset of the disability. Fitting and assembling the orthosis requires no tools. In a supine or sitting position, the patient is able to put the device on with no assistance in less than 3 minutes. This orthosis is attached to the lower extremities in trousers similar to ordinary blue jeans. The usual method of trousers adaptation is the simple sewing of textile pockets to the lateral side of the trouser legs.

SFMOs are equipped with cybernetic actuators (CA). Three phenomena could be achieved with CA: anisometric contraction (flexion and extension of the joint), isometric contraction

(locking of the joint in the desired position), and damping-control/stiffness-regulation. The CA is equipped with nonlinear limiters to prevent jerking and is electrically powered, enabling several hours of daily locomotion between battery charges.

It is accepted that walking with calipers is less effective than wheelchair propulsion or functional electrical stimulation (FES) gait, that patients do not like the weight of an active brace, that they are permanently exposed to the danger of suffering from pressure sores, and that psychological acceptance is extremely low. The proposed new method of gait restoration, HAS, is a combination of FES and external bracing controlled by an expert system. First experiments with quadriplegics and paraparetics encourage promoting such an approach as a step in the development of efficient motor neuroprostheses.

As it is known, FES is a very effective movement generator. Recruitment properties are superior compared to exoskeleton joint actuators if the upper motor neuron is affected. Total neurophysiological lesion of the upper neuron, lower motor neuron impairment, and muscle denervation prevent FES from being applied. An exoskeleton is excellent for providing body support without causing muscle fatigue, and when a soft interface is used, no pressure sores occur. Parallel action of these two systems with appropriate controls is called hybrid orthoses for motor restoration.

HAS components include the following:

- 1) A six-channel stimulator with surface electrodes. Each channel is activated independently; pulse rise is exponential; pulse width, IPI, and pulse frequency are under microcomputer control. This type of stimulation repre-

sents the modified principle used and developed by the Ljubljana group.

- 2) SFMOs with CA in hip and knee joints. Used for external bracing.

- 3) Sensors for feedback. Potentiometers, pendulum potentiometers, tacho generators, and a set of force transducers and switches built into the insole are used.

- 4) Microcomputer based on Intel 8085 microprocessor including appropriate input/output, parallel port, analog-to-digital converter, a clock, random access memory, and read-only memory.

- 5) Nickel-cadmium rechargeable batteries, used as a power supply.

Control methodology is based on non-numerical principles formulated in the form of an expert system. The knowledge base consists of production rules and expert knowledge in the form of so-called artificial reflexes. The learning is built into the system as well.

Preliminary Results—Testing of the system has been done in the “Dr. Miroslav Zotovic” Rehabilitation Center in Belgrade, Yugoslavia, proving some of the postulated qualities of the rehabilitative device: dynamics, safety, new range of functional movements, walking on slopes and stairs, etc.

In the present form of the system, there are certain limitations in range of movements arising from problems with stability, dynamic properties of the system, microcomputer capabilities, etc. The posture stability problem has not been solved, and hand support is in fact *sine qua non*. Decreasing hand-support forces—power expenditure through the upper part of the body for gait—is one of the main targets of system evaluation.

A Viscoelastic Knee Brace for ACL-Deficient Patients

M. Solomonow, Ph.D. and R. D'Ambrosia, M.D.

Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: United Cerebral Palsy of New Orleans

Progress—An orthotic design incorporating a constant velocity hydraulic chamber activated near the final segment of the swing phase to be

worn on the knee of patients with anterior cruciate ligament deficiencies was designed and evaluated. The brace reduces terminal impact

velocity of the knee's extension to speeds that will not induce joint instability without limiting the joint range of motion.

A patent was issued and assigned to a manufacturer for commercial distribution of the brace.

Standing Frame Lift Mechanism

Scott Griffith

Westinghouse Defense and Operations Division, Baltimore, MD 21203

Sponsor: *Volunteers for Medical Engineering, Inc.*

Purpose—A team of volunteers from the Volunteers for Medical Engineering, Inc. (VME) have been donating their time and talents to design and fabricate a Mobile Standing Frame that will allow the paraplegic person to stand and to wheel around as one would do with a wheelchair. A second purpose of the work is to develop a means for the handicapped person without upper body strength to transfer from the wheelchair to the Mobile Standing Frame without an electrically powered device.

Progress—The initial design is similar to one produced many years ago except that it now incorporates regular bicycle wheels and a unique braking system. We are presently building a production prototype for evaluation.

Some of the persons who could use this mechanism have a problem getting into the device from their wheelchair either because they have very little upper body strength or are insufficiently stable to maneuver into the standing position. A team of people is currently working on a tethered waistband system wherein the person using the frame is rigidly attached to the waistband section of the frame. This section is in turn attached to a cable that is also attached to the return coil spring mounted to the frame. Thus, when someone unlatches from the main frame, the individual is still at-

tached via the cable to the frame and the associated coil spring.

As the person bends at the knees to begin to sit down in the wheelchair or any other seat, the spring extends and the spring-loaded tether begins to increase its tension. The force exerted by the spring is tailored to the forces needed to just suspend the person. Therefore, when the person wishes to again rise from the seated position, very little upward force is required for this action.

A person may disconnect from the tether by latching the spring-loaded cable tether in the fully extended position and, with the twist of a lever, disconnecting the waistband from the tether attachment. One is then free to leave the standing frame. An individual may get back onto the Mobile Standing Frame by simply reattaching the waistband to the tether and releasing the catch so that the cable is again free to pull on the waistband and in so doing raise the person to the standing position.

Future Plans—The design and analysis will be continued, and the layout of the tether mechanism will be completed. Proposals will be submitted to the VA, to the Paralyzed Veterans of America, and to other agencies soliciting their aid for funding of this ongoing project.

Design of External Joint Assemblies Using CAD-CAM Techniques

Peter S. Walker, Ph.D.; Joshua Rovick; Robert Schrager ; Mark Madson

Veterans Administration Medical Center, West Roxbury, MA 02132

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The goal of the project is to automate the design of orthotic surfaces and external

hinges for application to the knee, elbow, and other joints.

Efforts thus far have centered on the design and prototyping of a data acquisition system for three-dimensional digitization of body surfaces. Initially, various commercially available technologies were investigated. They lacked 1) ease of use and adjustability for different body surfaces; 2) cost-effectiveness; and 3) any means for collecting information on the material properties of the tissue. For these reasons, we pursued a prototype design for a general-purpose, medium-cost, and direct-contact method of digitization.

Progress—The initial prototype may be described as a mechanical hand whose spring-loaded fingers run along the surface to be digitized while maintaining a constant contact force. When a button is pressed, the host computer (Apple IIe) stores the angular position of the fingers with respect to the hand and concurrently locates the hand's position in space using a six-degree-of-freedom electromagnetic sensor available from Polhemus Navigation Systems. The surface points may then be reconstructed relative to a fixed axis system. Data acquisition speed is limited by the 60-Hz sampling rate of the sensor; with the two fingers presently incorporated, data acquisition speed is limited to 120 points per second, but the speed could be increased to 480 points per second by utilizing eight fingers. Information about the material's compliance can be obtained by varying the constant force exerted by the fingers in subsequent digitizations and noting shape change.

Software was written to allow data acquisition, geometrical reconstruction of the digitized points, and graphical presentation of the X, Y, Z data points. For resolution, accuracy, and reproducibility analysis, programs that calculate digitization error from standard shapes such as planes, solid blocks, and cylinders, were developed and are being used to identify error sources. The data so far have indicated that the coordinate error has a standard deviation of about 1 mm.

Preliminary Results—Three problems need to

be overcome before the data generated by this technique can be used. The first is that of data reduction: the user, in order to ensure that enough data points have been taken to describe the surface adequately, will make multiple passes over the same area, resulting in what will often be "too much" data. By filtering recursive points, the programs will run faster and more efficiently. Before this algorithm can be fully developed, a number of initial estimates must be examined to determine the magnitude of data that is sufficient to describe a surface.

The second problem concerns surface reconstruction. Because of the error inherent in the system, as well as the potential for motion of the surface during digitization, there will most assuredly be some three-dimensional displacement of successive groups of points, e.g., those generated from different strokes of the fingers. Because this displacement can include components of both translations and rotations, the problem of correlating data is a significant one. To date, the majority of the work done on this problem has been in the form of a literature search. Some mathematical algorithms involving bicubic parametric patch geometry principles have been developed that will be coded and tested on data generated by artificially inducing error into mathematically described surfaces.

The third problem is that of surface smoothing. The necessary conditions of the patch algorithm perform smoothing to some extent, assuring that adjacent patch segments are continuous in position, as well as first and second derivatives. Nevertheless, some additional smoothing, in the form of postprocessing, will most likely be necessary. As with the above problem, a number of algorithms that perform surface smoothing are available and are currently being studied.

Future Plans—A computer numerically controlled milling machine (CNC) will be interfaced to a MicroVax II computer system. Using a redesigned prototype digitizer and computer surface reconstruction algorithms, body surfaces will be replicated with the CNC. These

tools will then be used to study and parameterize body surface shapes, build anthropometric

databases, and begin automated External Joint Assemblies (EJA) design.

Orthotics

J. D. Harris; C. Eng; M. W. Whittle, M.D.

Oxford Orthopaedic Engineering Centre, Oxford University, England

Sponsor: U.K. Department of Health and Social Security

Progress—Assessment has been carried out on a wide range of lower limb orthoses in a gait laboratory with the "Vicon" motion analysis system and two "Kistler" force platforms. As a direct result of this work, an anti-hyperextension brace has been developed that reduces the shock impact to the posterior capsule of the knee on full extension while permitting normal knee flexion.

Another orthosis developed at the Centre is the "Cherwell" ankle foot orthosis, which provides valgus foot support while allowing flexion of the ankle. This is achieved by means of a

closely fitting polypropylene calf support and a separate foot cup, joined by a carefully aligned hinge at the ankle. The freedom of movement of the ankle joint while supporting the subtalar joint and the foot greatly improves walking, particularly over uneven ground, and allows activities such as driving. A "modular shoe" concept has been developed that allows patients who cannot be fitted with stock size shoes to be provided in approximately 1 to 2 hours with a pair of well-fitting shoes from a range of styles. The shoe is of a three-part modular construction assembled by means of adhesives.

Lightweight Knee Joint for Child-Size Orthoses

Ian R. Mortimer; William E. Fisher; Barry R. Seéger

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: Rehabilitation Engineering Department, Regency Park Centre for Young Disabled

Purpose—Current knee-ankle-foot orthoses usually consist of molded thermoplastic cuffs with metal knee joints, which are the heaviest components. Excessive weight in orthoses can be an impediment to greater mobility with smaller children. This project aims to develop a lightweight plastic knee-locking joint that is easily fixed to the plastic thigh and lower leg cuffs of the orthoses.

The new joints will be lighter in weight

than existing metal joints, will have a more acceptable appearance, will be smoothly finished to avoid clothing damage, and will be available in free or locking types. Prototype joint design and testing is in progress, with completion of the development expected in 1987.

This project is being conducted in collaboration with the School for Mechanical Engineering, Regency Park Community College.

Development of a Powered Orthosis for Lower Limbs

Yasuhisa Sakurai; Hiroyuki Miyamoto; Yoichi Shimazaki; Kenji Tokimura

Institute of Biomedical Engineering, Tokyo Women's Medical College, Tokyo, 162 Japan

Sponsor: Office for Life Science Promotion of the Institute of Physical and Chemical Research, Agency of Science and Technology, Japanese Government

Purpose—To obtain an appropriate gait pattern, a powered orthosis for paralyzed lower

limbs is being developed that supports the patient's body and controls lower limb movement.

As a final goal, the powered orthosis will enable paraplegic patients to walk on level ground with a variable cadence, to stand and sit, and to go up and down a staircase by appropriate command.

Progress—The first prototype of the powered orthosis has been developed, consisting of an exoskeletal frame to support the body and four electrohydraulic linear actuators to motorize hip and knee joints. A microcomputer and sensory system are used to generate and control the prescribed gait pattern. This gait pattern should be modified according to the patient's actual walking condition. A posture sensor has been developed and used to control the center of gravity displacement so that a stable powered walk can be obtained. It is attached on the orthosis and operates independently of environmental conditions.

Two control methods have been studied on normal subjects to evaluate the effectiveness of each method: 1) an autonomous powered walk by the use of a posture sensor; and 2) interactive control with crutches.

Preliminary Results—By method 1, continuous even-level walking and a transient movement from the upright state into level continuous walking was realized on a normal subject by controlling the trajectory of the center of gravity. We verified that powered walking is stable

even in the presence of some disturbances. In 1985-86, transient movement from walking into the upright state was realized using the posture sensor.

By method 2, several essential level-walking movements such as beginning and ending the walk, continuous walking, and change of cadence were realized. Climbing up and down a staircase was accomplished in 1985-86. The ease of operating the command was verified; the patient can start or stop the powered walking by lifting one of the crutches or by keeping them in contact with the ground for a specified period of time. The patient can regulate the cadence by changing the timing of lifting the crutches during walking.

Some additional studies are being carried out to simplify the communication between the patient and the powered orthosis-walking state display to enable the patient to feel upper torso inclination, to feel how the center of gravity is moving via posture, and to feel when the feet are in contact with the ground. It allows the patient to operate the powered orthosis in order to accomplish a stable powered walk.

Future Plans—A second prototype of the powered orthosis will be constructed and evaluated on paralyzed patients. Most of the analog control instruments will be replaced by digital ones to improve control and reliability of the system.

Molded Shoe

Peter M. Graf, D.P.M. and Richard M. Stess, D.P.M.
Veterans Administration Medical Center, San Francisco, CA 94121
Sponsor: VA Rehabilitation Research and Development Service

Purpose—This project was undertaken to fabricate a molded shoe, using foam injection technology already established in the commercial shoe industry, at markedly reduced cost (approximately \$10 per pair) and at significantly shortened delivery time (48 hours or less) with no loss of therapeutic effectiveness. Such a shoe would be useful in the treatment of patients suffering from foot problems secondary to vascular disease, diabetes, deformity, arthritis, and

peripheral neuropathy.

Progress—A prototype ultrasonic range-of-motion measuring instrument was developed and utilized to assist in capturing the foot in a biomechanically efficient position. A tubular fiberglass resin foot casting system was developed in collaboration with the 3-M Corporation. Both control and at-risk patients were selected via screening procedures established jointly

with the departments of metabolic endocrinology, radiology, and podiatry. Ultrasound, thermography, aesthesiometry, and doppler imaging were utilized in risk stratification.

A small on-station shoe manufacturing laboratory was established to evaluate various methods and materials in custom shoe design. The purchase of a Resimix polyurethane injection molding unit allowed evaluation of foam material and its usefulness in custom-molded shoe design. Functionally molded sandals were

fabricated for a material cost of less than \$10 and in less than an hour of bench time.

Future Plans—The following devices will be developed, tested, and refined: 1) an electronic measuring instrument to accurately position the foot while it is being caste; 2) a mechanical casting system to duplicate the boot being caste; and 3) an injection molding system and variable shape mold.

Bioengineering Research and Development at Instituto Mecánica Aplicada (IMA)_____

L. C. Nava and P. A. A. Laura

Instituto de Mecánica Aplicada (CONICET) Base Naval Puerto Belgrano 8111 Argentina

Sponsor: *Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina*

Purpose—Work in the Applied Bioengineering Section of the Instituto de Mecánica Aplicada has continued in the last 3 years in the following directions: rehabilitation engineering, sports for the disabled, and optimization of general medical and/or hospital equipment.

Cuff-Adjustable Forearm Crutches. The efficient mechanical operation of forearm crutches requires a quasi-perfect compatibility between the hand and forearm of the handicapped and the orthotic device. This compatibility requirement is based on geometric, kinematic, and dynamic conditions. The forearm-cuff fit is a fundamental parameter. Crutches with cuffs adjustable in a continuous fashion developed at IMA have proved extremely successful in the

case of handicapped children.

The IMA Brace for Deambulatory Treatment of Legg-Perthes Diseases. The IMA II brace offers several advantages in comparison with conventional braces designed for use by children. Highly improved kinematic characteristics are obtained by the use of six joints placed symmetrically at two levels of the brace. A basic feature of the present device is that it simulates the pumping effect produced by the congruent movement between the femoral head and the acetabulum, resulting in activation of the circulation in the femoral head. On the other hand, the design of the brace is such that it minimizes the restrictions placed on the child's daily activities.

III. Total Joint Replacement and Other Orthopaedic Implants

A. General

The Effect of Notching of Simplex-P Bone Cement on the Fatigue Lives of Regular Versus Vacuum-Mixed Specimens

Eugene P. Lautenschlager, Ph.D.; Fawwaz I. Hamati, Ph.D.; Michael A. Novak, D.D.S.; Richard L. Wixson, M.D.
Northwestern University, Chicago, IL 60611

Sponsor: *National Institute of Handicapped Research*

Purpose—It has been shown that a partial-vacuum slow-speed system for blending of the liquid and powder components of Simplex-P produces set acrylic bone cement specimens of less than 1 percent porosity with significantly improved uniaxial tensile fatigue lives over regularly mixed cement. However, those tests were conducted using smooth-machined specimens, which may not necessarily be clinically comparable to the *in vivo* condition of an irregular interface with cancellous bone. In the present study, the influence of cement surface condition on fatigue life was investigated with specimens having either machined 60-degree notches or cast into collars of cancellous bovine bone. These were compared with smooth-machined specimens.

Progress—Vacuum-mixed fatigue specimens were prepared from iced, prechilled components by pouring the powder into the entire quantity of liquid. A vacuum of 550 mm Hg was then applied to a high-strength reinforced bowl for 90 seconds, during which mixing was done at 1 blade revolution per second. Regular mixtures were prepared by hand spatulating room-temperature powder and liquid. Fatigue specimens were made by placing the admixtures into a caulking-gun-type syringe and extruding the material into 8-mm-ID x 80-mm-long glass tubes. For the collar specimens, an 8-mm-OD, 6-mm-ID x 20-mm-long bone tube was centrally

positioned in the glass tube prior to cement insertion. After 1 week storage in 37-degree Centigrade water, the machined specimens were reduced to 6 mm diameter in the central 20 mm. Additionally, the notched specimens received a centrally placed 0.25-mm-deep, 60-degree, 0.08-mm-tip radius notch. Testing was conducted at room temperature at 2 Hz in a Model 1350 Instron cycling sinusoidally from 1.5 to 20 MPa until fracture.

Preliminary Results—The results of the fatigue studies show the data for all eight specimens of each group are drawn as slopes on Weibull paper. Machine notching reduces the fatigue life of bone cement, and the machine also increases the scatter in the data. However, even in the machine-notched condition, vacuum mixing is superior to either the regular-smooth or regular-notched condition.

In the Weibull mean fatigue lives, the notching created by the bone collars, although not quite as severe as machine notching, also reduced the fatigue life as compared to smooth machining. Again, under all surface conditions, vacuum mixing was significantly better than regular mixing.

Loosening, with breakdown at the bone/cement interface, remains a major cause of long-term failure of total joints. It is not yet known if stronger cements, achieved by mixing under partial vacuum, will reduce the incidence

of loosening. This study does show that even with areas of increased stress concentration from surface irregularities similar to that at a

bone/cement interface, vacuum mixing allows the use of a more fatigue-resistant material for cemented total joints.

Bone Remodeling Around Ingrowth Joint Implants

Richard L. Wixson, M.D.; Jack L. Lewis, Ph.D.; Neal Elasky, B.S.; Edward Klinenberg, M.S.
Northwestern University, Chicago, IL 60611

Sponsor: *National Institute of Handicapped Research*

Purpose—The objective of this project was to develop an animal model for studying bone remodeling around ingrowth implants and then to compare cancellous bone remodeling with a three-dimensional finite-element model of the animal model. The purpose of the comparison was to determine if remodeling could be predicted by a simple linear elastic model.

Progress—An animal model consisting of a surface replacement hip component in the dog was developed. Components with porous surface and surgical tools for installation were designed and manufactured. The components were implanted in four animals, two sacrificed at 3 months, and two at 6 months. The femoral heads of each animal were sectioned, with metal in place, and specimens prepared for histology, microradiography, and mechanical stiffness testing. Control specimens from the contralateral limb

were also tested. A three-dimensional finite-element model of one of the femoral heads was constructed and run.

Preliminary Results—Results showed poor reproducibility of the bone remodeling response, even though the surgical technique was considered to be quite precise and relatively reproducible. All four animals showed remodeling, but there were significant differences between each pair of animals. This variability precluded any meaningful prediction of remodeling with the finite-element model. There was positive, but weak, correlation between changes in mechanical stiffness and area fraction. The results suggest that some other variable not controlled in the experiment was influencing bone remodeling. This factor, or factors, must be understood before useful predictions of bone remodeling can be done.

Investigation of the Bone/Bone Cement/Implant Interface Formed by Total Joint Replacement

Jack L. Lewis, Ph.D.; John W. Steege, BSME; Richard L. Wixson, M.D.; Phil J. Branson, M.D.; S.D. Stulberg, M.D.; Ted Polizos
Northwestern University, Chicago, IL 60611

Sponsor: *National Institute of Handicapped Research*

Purpose—The objective is to identify and quantify the causes of late loosening of total joint replacement components by examining several aspects of the interface system.

Progress—Factors Affecting the Mechanics of Bone/Bone Cement/Interface Failure: Fatigue data were generated for bimaterial (bone-poly-methylmethacrylate) four-point bending test

specimens. Conceptualization of crack growth data was achieved as a series of stable growth periods interrupted by discrete occurrences of cement posts characterized by zero crack growth. Results of previous finite-element models of the test specimen with and without a cohesive zone present at the bone-PMMA interface were employed in determining the cyclic stress intensity factor (ΔK) at the crack tip.

Preliminary Results—Multivariate statistical analysis was performed on the data in attempts to: 1) relate crack propagation rate ($\Delta a/\Delta N$) to ΔK , PMMA penetration depth, and bone strength for the stable crack growth periods and 2) relate the same factors to the number ($Post_N$) and duration (ΔN_{post}) of zero crack growth periods. A predictive equation was obtained along with statistical significance levels for the modeled crack growth behavior. In all, 26 specimens were tested. In general, results indicated an inevitable formation of an interface crack. Crack growth, however, was retarded by increased cement penetration, bone strength, and $Post_N$, whereas the inclusion of a cohesive zone played little role in the final results.

It was proposed to enhance the interface by the introduction of artificial posts. The proposed post density was obtained by optimization of the predictive equation for $Post_N$. Based upon the optimized results and several biomechanical considerations, a "crack arrestor" device was designed for and tested qualitatively in the four-point bending test specimen. Results were very encouraging, and work is continuing on further development and study of the "crack arrestor" concept. An abstract was prepared and submitted to the 1987 Orthopaedic Research Society meeting.

Failure Mechanisms in PMMA Around Tibial Components: A demonstration pilot project was undertaken to examine failure mechanisms in PMMA around loaded tibial components. Tibiae with cemented components were cyclically loaded, sectioned, and examined with a scanning electron microscope. Residual gaps between cement and implant were noted as well as microcracks surrounding cement voids and inclusions.

Workshop on the Implant Interface: The proceedings of the workshop held September 1983 entitled "The Bone-Implant Interface Workshop Report" was published by the American Academy of Orthopaedic Surgeons in 1985.

Fixation of Noncemented Knee Compo-

nents: This study attempted to quantify the motion occurring between bone and ingrowth component to better understand the role of relative motion in ingrowth failure.

Fresh tibial specimens were potted in PMMA 12 cm below the joint line. The proximal articular surface was milled flat and perpendicular to the sagittal long axis of the bone. The appropriate porous component was impacted axially for rigid fixation in the 12-percent interference fit of the fixation pegs. Liquid metal strain gauges were cemented to the tibial plate and proximal 5 mm of the tibia anteromedially, anterolaterally, posteromedially and posterolaterally, and anteriorly in a stepwise fashion from 10 to 2000 Newtons. Testing was aborted at .5 mm bone/plate separation. The plate and gauges were then removed and the prosthesis cemented into place. The gauges were remounted and the loading sequence repeated.

Motion between the implant and bone was reliably detectable with the naked eye at 200 to 300 microns. Visible separation between the implant and bone of > 0.3 mm occurred with posterolateral loads of 20 to 200 N. Medial separation with posterolateral loading occurred at higher loads, from 150 to 1500 N. Noncemented anterior loading was performed in four cases, and posterior separation was noted between 20 to 200 N. The medial peg was consistently difficult to extract, even after visible separation of the implant from the plateau, suggesting the interference fit remained secure. Gross bone/implant motion was not observed in cemented applications.

Maximum oscillatory, inducible, elastic deformation of noncemented components ranged from 6 to 290 microns, as compared with the cemented range of 0 to 99 microns over an increasing axial central load of 10 to 2000 Newtons ($p < .04$). Posterolateral loads from 10 to 300 Newtons resulted in maximum noncemented inducible motion of 30 to 200 microns as compared to cemented motion of 4 to 93 microns ($p < .05$).

Mechanical Properties of Trabecular Bone Tissue

Jack L. Lewis, Ph.D. and Peter Mente, B.A.

Northwestern University, Chicago, IL 60611

Sponsor: *National Institute of Handicapped Research*

Purpose—Bone remodels around total joint implants, changing the mechanical state of the load transfer across the bone-implant interface. It is of interest whether the cancellous bone changes its porosity only or the mechanical properties of the trabecular tissue as well. The objective of this project is to develop a test technique to measure the stiffness of individual trabecula and then to use this technique to measure the stiffness of trabecular tissue from the proximal tibia of normal and diseased subjects.

Progress—The method chosen was to first measure the load deflection of a single trabecular piece as a cantilever beam, to model this piece of bone by a three-dimensional finite element model, and then to simulate the mechanical test on the model. Stiffness of the bone piece is determined by matching the experimental and finite-element models. During this report period, each of these tasks was accomplished.

The procedure consisted of: 1) isolate a single piece of trabecular bone shaped like a rod or beam (the piece need not be of exact regular shape); 2) pot one end of the piece in epoxy, forming a cantilever beam; 3) fix the potted specimen in a test fixture with a movable stage, an LVDT displacement transducer,

and a 60-g load cell; 4) perform a load-deflection test on the bone piece. The specimen was then removed from the fixture, potted in a cylindrical mold to totally encapsulate the bone piece, and ground down axially, with photographs taken of cross-section every 0.25 mm. These sections were then digitized and used to create a three-dimensional finite-element mesh using the program NUFIG. Boundary conditions appropriate to the experiment were then added and the program run to predict a deflection due to the experimental force. Stiffness of cortical bone was assumed for the run. Actual stiffness of the trabecular bone was deduced by matching the experimental and finite-element deflection by changing the material stiffness (this could be done because the problem was linear).

Preliminary Results—Five specimens have been tested, three from a dried and rewetted tibia, and two from a fresh tibia. Average Young's Modulus predicted was 0.53×10^{10} N/m², (with a range of 0.12 - 0.2), compared to 1.5×10^{10} N/m² for cortical bone. The results suggest that cancellous bone has a different stiffness than cortical bone and cannot be considered simply as cortical bone with holes in it. The work is continuing to further verify the technique and to measure more specimens.

Expert Manufacturing System for Custom Prosthesis

R. Larry Dooley, Ph.D. and Edward W. Berg, M.D.

Bioengineering Alliance of South Carolina, Clemson University, Clemson, SC 29634 and William Jennings Bryan Dorn Administration Medical Center, Columbia, SC 29203

Sponsor: *VA Rehabilitation Research and Development Service and Bioengineering Alliance of South Carolina*

Purpose—In many degenerative joint and bone diseases of the disabled veteran there is the need for a custom-designed prosthesis to accommodate patient anatomical peculiarities. Presently, 6 to 8 weeks are required to manufacture a custom prosthesis. Several research centers in the United States have attempted recently to

utilize computer-aided design/computer-aided manufacturing (CAD/CAM) technology to reduce the manufacturing time for a custom device. They have had limited success because the design activity requires interdisciplinary expertise in biomaterials, biomechanics, orthopedics, and CAD/CAM.

Progress—We are investigating using artificial intelligence (AI) technology combined with CAD/CAM to create a prosthesis design expert system. We are developing radiographic techniques combined with special 3-D computer graphics software that will enable a patient's joints to be modeled on the computer screen. By using AI, finite-element stress analysis, a database of normal joints, and interaction with the clinician, the expert system will determine dy-

namic joint forces and evaluate off-the-shelf prosthetic devices. If an off-the-shelf prosthetic device is determined to be unacceptable, a prosthetic device will be fabricated using machine tools controlled by the computer.

Preliminary Results—Preliminary software development is proceeding. Results to date are very encouraging.

Porous Polyethylene as a Reconstructive Material

Harold I. Friedman, M.D.; Arun Shanbhag, B.E.; Andreas F. von Recum, Ph.D., D.V.M.; Francis W. Cooke, Ph.D.; Dennis L. Powers, D.V.M.

Bioengineering Alliance of South Carolina, Clemson University, Clemson, SC 29634-0905

Sponsor: VA Rehabilitation Research and Development Service and Bioengineering Alliance of South Carolina

Purpose—Porous polyethylene (PPE) can be cut and fabricated into a desired shape by the surgeon at the time of implantation and therefore appears to be an excellent material for reconstructive surgery. The goal of the project is to evaluate the tissue reaction of PPE and to determine its applicability in reconstructive surgery. To evaluate the material, the cartilage in the external ear of the baboon (*Papio cyanocephalus*) was removed and replaced with PPE. The stability of PPE in this location was used as an indicator of tissue response and applicability of PPE.

Progress—Sixteen test specimens were implanted in eight baboons. Eight-mm-diameter cartilage plugs were punched out of the external ear and replaced with a similar size PPE disc. Silastic rubber discs were used as controls. The test specimen implants were removed 8 weeks postoperative.

The removed implants were subjected to light and electron microscopic analysis. Light microscopy showed minimal capsule formation and vascularized tissue ingrowth in the well-stabilized PPE implants. TEM analysis sustained our tissue response and stability hypothesis. Mature collagen fibers were found adjacent to the implant material. The SEM study demonstrated that PPE could be cut on the operating table with a scalpel. The cut surface is smoother and results in less tissue reaction. The second group of eight implants were recently implanted in four baboons. The results are not currently available. PPE used for this experiment is characterized physically and chemically.

PPE appears to be an excellent material for reconstructive surgery. Our studies indicate no adverse tissue reaction, and the material is approved by the Food and Drug Administration for surgical use.

Bone Remodelling Around Porous-Ingrowth Implant

Dennis Carter, Ph.D.; Tracy Orr, M.E.; Cary Tanner, M.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94303

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This project investigates the remodeling behavior of a rabbit femur model in response to changes in bone stiffness. The rabbit

femur model involves implanting a porous-coated metal rod, attached to a hind limb, in immature (10 weeks) rabbits. After 16 weeks

the rabbits are sacrificed and the mechanical and physiological changes in the bone are assessed using tetracycline labels and radiographic, mechanical, and histomorphometric methods. Questions to be answered are:

1. What are the initial changes in cyclic strains in the rodded and contralateral femurs?
2. What are the temporal changes of bone mass in response?
3. How do the bone changes manifest themselves in the structural properties of the bones?
4. Does the contralateral limb hypertrophy in response to changes in loading?

The ongoing work of our research program has resulted in the development of a conceptual framework in which the structural adaption of cortical bone can be viewed. This framework has been formed with an appreciation of the mechanical role of bone in living animals and the response of whole bones, bone tissue, and bone microstructure to various loading histories. This study will be the first step in the continuation of our research in understanding the mechanisms of bone remodeling and could have implications in the design of porous-ingrowth prostheses.

Fracture plate implantation has been used to study stress-related bone loss and recovery. However, the trauma imposed by the implantation procedure (even without osteotomy) clouds the issue of bone stress- or strain-related re-

modeling. Plates which provide little stress shielding can actually cause new bone deposition and a net increase in whole bone structural rigidity. Those results indicate that caution should be exercised when evaluating bone hypertrophy in response to invasive procedures designed to increase bone loading—hypertrophy may be wholly or partly achieved by non-stress-related phenomena. It is for this reason that a less destructive animal model has been designed and developed.

In this study, a 40-mm-long Co-Cr alloy (a material used in existing clinical prostheses) rod with a porous coating is attached to the right femur of 10-week-old New Zealand white rabbits by banding the femur at each end of the rod. The left femur is used as a control.

Progress—The experimental procedure has been completed on 8 of the 14 rabbits currently under study. The femurs have been embedded and sectioned for thick-section microscopy.

Future Plans—Thin-sectioning and histological examination await the development of a more dependable thin-sectioning technique.

The next step will be to compare control animals (no rod implanted) with the experimental animals. During that phase, the effects of loading on bone remodeling will be studied by placing weights on the animals.

Biomechanics of Bone Resorption/Regeneration at a Bone Implant Interface

G.V.B. Cochran, M.D., M.Sc.D. and J. Brunski, Ph.D.

Helen Hayes Hospital, W. Haverstraw, NY 10993 and Surgical Research Service, Castle Point, NY 12511 and Rensselaer Polytechnic Institute, Troy, NY 12181

Sponsor: VA Rehabilitation Research and Development Service and New York State Department of Health

Final Report—The relationship between bone remodeling and mechanical stresses in bone has vital implications!with respect to the interaction between surgical implants and bone. The objective of this study is to gain knowledge of the physiological reactions of bone in relation to mechanical stress at the interface between bone and an orthopaedic implant such as a joint replacement or device for fracture fixation. The research has attacked the problem by

means of special titanium screw implants in canine bone. Three months following the insertion of the screws, they are subjected to a programmed loading regimen by an external device. Stresses at the interface and within adjacent bone are calculated by finite-element analysis, while the bone reactions are determined by quantitative histology and compared with local stresses. Because successful joint replacements are dependent on secure and per-

manent fixation in bone, this study represents an unusual attempt to improve implant design by examining the effect of local stresses on bone.

In the course of this project, we demonstrated that the state of bonding or adherence between bone and the implant is a major factor in the stress patterns produced. Thus, we identified this factor as a significant variable that must be controlled. In addition, we developed techniques for assessing the effects of loading on the bone-implant interface and applied them to special screw implants in canine radius and mandible. For both locations there were instances of statistically significant differences between loaded and unloaded cases, although

no differences were detected on a group basis, the standard loading regimen for this study. Further work with these techniques should enable us to identify stress levels that encourage maintenance of a healthy bone-implant interface. Implants can then be designed to generate these stress levels during normal physiological activities such as walking.

The next phase of this project, "Determination of Effects of Implant Interface Mechanics on Bone Remodeling," has recently been approved. During this study we will investigate effects of loading regimens producing higher stress levels over longer periods on our existing model, as well as investigate the interfacial bone response to micromotion.

Evaluation of Total Joint Implant Loosening Using X-Ray Photogrammetry_____

Frederick G. Lippert, III, M.D. and Sandor A. Veress, Ph.D.
Veterans Administration Medical Center, Seattle, WA 98108

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to develop a clinically-applicable system for measuring relative motion between the components of total joint implants and the bones into which they are placed in order to evaluate the loosening or migration of the components.

Progress—Radiographic markers are placed in the bone and total joint components and displacements are measured with two- and three-dimensional X-ray photogrammetry systems under various loading conditions or as a function of time since surgery. Research subjects are placed in a calibration framework and exposed to X-rays from two anodes. The images of the radiographic markers in the bone and components are measured on an accurate coordinatograph, and their three-dimensional coordinates calculated. Changes in the relative posi-

tions of the markers with time or loading indicate looseness or migration of the total joint components.

Results—No patients were studied this year. A new calibration frame was completed. This frame allows the X-ray cassettes to be positioned perpendicular to the anodes. The accuracy of the frame was tested using a cylinder containing two movable Plexiglas components. The position of the components was changed and measured with a micrometer. At the same time, X-ray photogrammetry was used to measure the same change in position. On the basis of these experiments, substantial improvement has been made in the ease and accuracy of this kind of X-ray photogrammetry measurement. In addition, software evolutions have made the computer phase more user-friendly.

The Efficacy of Radiolucent Low Modulus Total Hip Surface Replacement

Harry B. Skinner, M.D., Ph.D. and Stephen D. Cook

Veterans Administration Medical Center, San Francisco, CA 94121 and Veterans Administration Medical Center, New Orleans, LA 70146

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to investigate the potential of using a radiolucent low-modulus surface replacement as a prosthesis for the hip. This study is a bone remodeling study in that a comparison of the cancellous bone under a carbon femoral surface replacement is to be compared to the normal cancellous bone in the contralateral hip. In addition, the bone under a carbon femoral prosthesis is to be compared directly to the cancellous bone of the contralateral femoral head that has been resurfaced with a cobalt chromium prosthesis of a much higher modulus.

Preliminary Results—At this point, all of the unilateral carbon replacements have been retrieved and are undergoing quantitative trabecular stereology. All of the bilateral replacements have been implanted and were retrieved by January 1986. These then underwent histo-

logic examination and quantitative trabecular stereology. Finite-element studies of the femoral head with the carbon and with the cobalt chromium prosthesis are under way, and preliminary results have been obtained that must eventually be compared to the results of the quantitative trabecular stereology.

Computerized tomographic scanning of the unilateral and normal control hips has been performed. The data obtained from these studies will also be compared to the results of the quantitative trabecular stereology for those animals with a carbon surface replacement.

In an attempt to improve the finite-element studies, an algorithm has been developed for use on CT scan data to define trabecular pattern so that this information may be included in finite-element modeling. At present, work is progressing on using CT scan data to generate finite element meshes.

Implant Fixation by Postinsertion Pressurization of Polymethylmethacrylate

F. Richard Convery, M.D. and Savio L-Y Woo, Ph.D.

UCSD Medical Center, San Diego, CA 92103-9981

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Aseptic loosening of cemented joint arthroplasties remains the major cause of long-term failure. Many investigators have demonstrated significant improvement of penetration and mechanical strength using higher cement injection pressures; however, other studies have shown increased local and systemic toxicity with increased pressure. This project was designed to evaluate the effects of clinical (20 p.s.i.) versus high (100 p.s.i.) sustained pressurization of cement on systemic toxicity, local toxicity, and structural properties.

Progress—The current investigation is twofold. First, an *in vitro*, dynamic testing of mechanical properties uses fresh canine stifle joints,

with randomized sustained pressures of 20 versus 100 p.s.i.. Pull-out, push-in, and cyclic testing is evaluated for structural data. Second, an *in vivo*, time-0 canine study of 20 versus 100 p.s.i. sustained pressurization evaluated systemic and local toxicity, cement penetration, mechanical strength of the bone/cement composite, and an evaluation of weightbearing after total knee replacement.

Preliminary Results—Results of the *in vitro* structural and mechanical testing show a trend toward increasing stiffness at 100 p.s.i.. Load deformation and energy absorbed were not significantly different.

Results of the *in vivo* investigation show

that in this model there was no evidence of increased systemic toxicity with increased pressure. No significant difference was found for any of the measured cardiovascular parameters. There was no demonstrable hypotension or hypoxemia. Monomer blood levels were not significant, and fat droplet counts were low and unrelated to pressure. A transient change in one animal was later explained when postoperative X-rays demonstrated cement leakage around the medullary plug and filling of the unprepared diaphyseal canal. Histology for bone quality assessment, cement penetration, vascular disruption, osteonecrosis, and interface morphology is in progress. Microradiographs suggest increased filling of peripherally penetrated voids, greater osteonecrosis of the entombed trabeculae, and increased devascularization at 100 p.s.i.. This, with the early histology results, suggest a possibility of local toxicity, but it is too early to state whether this will be significant or have long-term effects.

A separate study has just been concluded investigating push-out and fatigue studies of the bone/cement interface using cross-sectional bone slices. No significant differences were found between pressures of 20 and 60 p.s.i.; however, proximal bone slices had a significantly greater interface shear strength than did distal slices. No significant difference was found for interface fatigue strengths.

Future Plans—Currently, plans for the project include the completion of the *in vitro* mechanical testing and the outstanding histology.

Projected plans include a long-term loosening study of sustained pressurized cement. The canine model proved successful in the time-0 study; therefore, total knee arthroplasties are planned on mongrel canines with studies at 3-, 6-, and 12-month intervals. The pressure to be used will be derived from the time-0 study after all data have been evaluated.

Development of Biologic Cement for Fixation of Skeletal Implants

Robert E. McLaughlin, M.D.

Rehabilitation Research and Training Center, University of Virginia, Charlottesville, VA 22908

Sponsor: *National Institute of Handicapped Research*

Purpose—The objective of the project is the development of biologic cement substances that can be used to stabilize artificial implants in bone and joint replacement surgery and to augment bone growth. Most of the current investigation is performed in animals. The work has direct clinical application in the fitting of porous-coated prostheses in bone-deficient elderly patients and in surgery resulting from failed prostheses.

Progress—Methods and materials to promote bone ingrowth into porous implants were investigated by immediate, short- and long-term (6-month) studies in a non-weightbearing canine model. The effect of two different preparations of an autogenous ground bone graft, demineralized bone matrix, and tricalcium phosphate, were studied. The main analytical technique involved measurement of forces required to pull

the implant out.

Preliminary Results—Autogenous bone graft of large particles was no more effective than the control at 6 weeks. Bone milled to a much finer and more uniform particle size had 125 percent more pullout strength at 6 weeks. Tricalcium phosphate packed around the implant produced a significant increase of fixation strength and provided as much stability as a press fit or as autograft immediately after implantation. At 6 weeks there was no significant difference between TCP augmentation and controls, but at 6 months, the TCP side was much stronger. The results with decalcified bone paste (biocement) were not significant at 2 weeks, but at 6 weeks showed a 44 percent increase in extraction force above the average control-side value and at 6 months the difference was further increased. Our conclusion is that ingrowth effects

are influenced by particle size and configuration. We also found that inorganic TCP filler enhances the immediate strength and that de-

calcified bone matrix significantly increases the long-term bony fixation of porous implants in the femoral canal of the dog.

Segmental Bone and Joint Replacement After Tumor Resection

Edmund Y. Chao

Mayo Foundation, Rochester, MN 55905

Sponsor: *National Institutes of Health*

Purpose—The emerging advances in adjuvant therapies for malignant bone and soft tissue tumors and the introduction of a surgical staging system to rationalize the extent and margin of tissue resection have renewed the interest in limb-saving procedures. The use of prosthetic implants based on the most advanced biomechanical design concepts and new implant materials appears to be very promising, not only to provide useful limb function for curable cancer patients but also as a palliative treatment to benefit those with metastatic lesions.

Progress—Two systems of metallic tumor prostheses were developed, but our clinical and laboratory results have demonstrated significant residual problems associated with these devices. Therefore, the currently proposed renewal is to achieve the following specific aims: 1) to develop a new nonporous coated modular tumor prosthetic system; 2) to modify the previous porous-coated modular prosthetic system and to examine the efficacy of extracortical fixation through bony ingrowth; 3) to investigate the adjuvant therapy effects on tissue incorporation into the porous implant; 4) to develop a method to attach soft tissue to the prosthesis; 5) to correlate patients' clinical assessment results with

their biomechanical functional evaluation results; and 6) to develop booklets for better patient home care and to write instructional manuals describing surgical techniques involving these prostheses. Bone geometric study and theoretical and experimental stress analyses will be performed to optimize the design of the modular systems. Dogs will be used as the models to investigate the biological, functional, and adjuvant therapy effects on prosthesis fixation through radiographic, histologic, and biomechanical analyses of the specimens. Established objective functional evaluation methods and techniques will be used to study the patient's functions and to correlate them with the clinical assessment criteria proposed by Dr. W. Enneking.

Future Plans—We plan to initiate a multi-institutional trial program after the new prosthetic systems are developed and tested. The long-term objective is to perfect two segmental bone/joint prosthetic systems that can be safely used on the majority of the patients with resectable primary tumors for restoration of function and on those with metastatic lesions for palliative purposes.

Weight Distribution in the Foot Before and After Surgical and Orthotic Intervention for Hallux Rigidus

James W. Moore, D.P.M.; David M. Garcia, D.P.M.; Avinash G. Patwardhan, Ph.D.; Gary Knight, M.S.
Veterans Administration Medical Center, Hines, IL 60141

Sponsor: *Langer Biomechanics, Inc.*

Progress—Hallux valgus deformity with limited motion and pain in the first metatarsophalangeal joint is associated with abnormal

weight distribution through the foot in ambulation. A common treatment modality for this condition is the Keller surgical procedure with

a total implant and the use of a functional posted foot orthosis postoperatively.

The goal of our study is to evaluate the efficacy of both the surgical technique and the functional posted foot orthosis in improving the biomechanics of the pathological foot in ambulation. We will measure the parameters characterizing the development of weight distribution

patterns in the foot within the environment of the shoe, using the electrodynogram. Our subjects will be patients who have been scheduled for the Keller procedure with a total implant at the Hines VA Hospital. We will complete the study over 12 months both pre- and postoperatively as well as with and without the orthosis after surgery.

Orthopedic Implant Retrieval and Analysis

Stephen D. Cook, Ph.D.; Kevin A. Thomas, Ph.D.; Marcus A. Kester, Ph.D.; Patricia M. Sandborn, B.S.
Veterans Administration Medical Center, New Orleans, LA 70146

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The implant retrieval and analysis research program continues to collect orthopaedic hardware from VA-affiliated medical centers. To date 6,233 patients' records have been accumulated. During 1985, 607 devices were inserted in patients at 3 VA-affiliated hospitals and 198 implants were removed routinely for justifiable causes.

Progress—An analysis of retrieved IM rods of the Kuntscher design based on clinical performance, metallurgical properties and corrosion characteristics was recently conducted. Dye penetrant failure showed no evidence of mid-shaft cracking in any rod; however, microstructural examination demonstrated the formation of small crevice corrosion cracks at the inside surface of the crimp in 10 of 18 rods. Increased surface corrosion was significantly correlated to inclusion content. Surface corrosion also increased with time *in situ* reflecting the use of inferior materials in early rods. This study also suggests that asymptomatic rods not routinely

removed are likely to be removed later for implant related complications.

The clinical and metallurgical performance of five fractured total hip stems has also been recently investigated to determine the mode of failure. Fatigue failure occurred in the cast cobalt-chromium-molybdenum hip stems after an average time of 7 years. Moderate to severe levels of gas porosities, interdendritic shrinkages and nonmetallic inclusions may have contributed to the failure of the device.

Results—Improper placement and material selection were the factors in the failure of fractured cast stainless steel unicondylar knee component evaluated. Due to posterior placement, only the anterior portion of the device was loadbearing, causing the distal portion of the device to be in tension. These tensile stresses coupled with observed carbides, inhomogenous grain size, nonmetallic inclusions and wear patterns lead to crack initiation and propagation and ultimately mechanical failure.

The Mechanical Properties of Porous-Coated Orthopaedic Alloy

Stephen D. Cook, Ph.D.; Nisra Thongpreda, B.S.; Ron Anderson, M.S.
Veterans Administration Medical Center, New Orleans, LA 70146

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This application of a porous-coating to a solid substrate offers advantages over current methods of implant fixation. However, fabrication of these devices commonly requires a

sintering heat treatment which causes a significant decrease in mechanical properties. Sintering Ti-6Al-4V alloy above the beta transus (992 degrees C) transforms the equiaxed microstruc-

ture, recommended for surgical implants, to a lamellar alpha-beta structure, which exhibits a significantly reduced fatigue strength.

Progress—In our studies to date, uncoated Ti-6Al-4V alloy having an equiaxed microstructure was found to have an endurance limit of 605 MPa. Both uncoated and coated samples were also examined after being subjected to a sintering heat treatment to produce a lamellar structure. The uncoated substrates displayed a 34 percent reduction in endurance limit and the porous-coated samples showed a large 77 percent decrease.

In an attempt to improve the mechanical properties of Ti-6Al-4V alloy, two different post-sintering heat treatments were used to produce microstructures different from the lamellar structure. The resulting microstructures were a fine and a coarse acicular. Mechanical properties such as yield strength, ultimate tensile strength, percent elongation, and hardness were determined from tensile tests performed on these two microstructures as well as the lamellar and as-received, equiaxed structures. As expected, the equiaxed structure exhibited the best properties: yield strength of 965 MPa, ultimate tensile strength of 1140 MPa, elongation of 13.50 percent, and hardness value of 32.90 R_C . The lamellar structure and both the acicular structures displayed comparable ultimate tensile strengths (~ 950 MPa) and hardness values (~ 26.86 R_C). The acicular structures showed slightly lower yield strengths (~ 735 MPa) than the lamellar structure (~ 825 MPa).

The most significant result was in the percent elongation. Both acicular structures exhibited greater elongation than the lamellar structure. The value for the fine acicular microstructure (9.8 percent) was statistically higher than for the lamellar (5.1 percent) and coarse acicular (6.6 percent) structures.

Results—In the present study, fatigue tests were performed on uncoated and coated specimens subjected to the two post-sintering heat treatments to produce the acicular microstructures. The results were compared to those previously obtained for the uncoated samples having the equiaxed structure and for the coated and uncoated samples having the lamellar structure. The endurance limit was found to be approximately 500 MPa for the uncoated fine acicular substrate and approximately 485 MPa for the uncoated coarse acicular substrate. This demonstrates a 25 percent increase for the coarse acicular structure when compared to the endurance limit of the lamellar structure. The porous-coated specimens for both acicular structures displayed similar results which exhibited an 18 percent improvement over the results obtained for the porous-coated lamellar specimens.

Based on the results of this investigation, it can be concluded that variations in mechanical properties occur due to microstructural changes. An improvement in resistance to crack initiation and propagation was observed for the microstructures produced by the two post-sintering heat treatments.

B. Hip

Quantitative Analysis of the Effect of Total Hip Arthroplasty on Stress and Strain in the Human Pelvis

R. William Petty, M.D. and Gary J. Miller, Ph.D.

Department of Orthopaedic Surgery, Veterans Administration Medical Center, Gainesville, FL 32602

Sponsor: VA Rehabilitation Research and Development Service

Purpose—With the advent of new acetabular cup designs and techniques for implantation, researchers hope to improve the overall performance of total hip arthroplasty. Historically, little objective experimental information is available concerning the effect of implantation of these devices on the stresses and strains developed in the human pelvis.

Using strain-gauge instrumentation, this long-term investigation quantifies the effect of available prosthetic components on the strains in the cadaver hemipelvis. Pelvic strain changes following implantation may predict the long-term success or failure of arthroplasties of the hip by delineating those implant designs or techniques that do not significantly alter the normal strain distribution of the pelvis.

Progress—Initial work has led to the development of an automated computerized data acquisition system and customized loading fixtures. This novel instrumentation allows for the simultaneous application of prosthesis loading and simulated muscle pull to allow assessment of surgical techniques and cup designs on pelvic strain during the simulation of single-limb stance.

In the early stages of this research endeavor, implantation techniques were carefully considered. More recently, the evaluation of cup designs has given rise to considerable information concerning the effect of implant rigidity on pelvic strain. Our most recent results would indicate that the compliant standard polyethylene components tend to increase the pelvic strains considerably, whereas thick walled cobalt-chrome metal-backed components actually unload or stress-protect the cadaver hemipelvis. Over the past year, titanium metal-backed components and thin-shelled cobalt-chrome metal-backed components with spacers have been evaluated. These more intermediate compliance components result in only small changes to acetabular strain.

Thus, it would appear, that strain changes in the pelvis may be controlled with implant compliance. This information, coupled with early clinical results obtained from utilization of these implant designs, should allow for determination of the design and methods that will lead to minimal strain changes and therefore improvement in the longevity of total hip arthroplasties.

Design Analysis of Porous-Ingrowth Hip Replacement

Dennis Carter, Ph.D. and David Fyhrie, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94303

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Cementless fixation of artificial joint components is one of the most potentially rewarding areas of research in orthopaedic research today.

It is well recognized that loosening is the major clinical problem associated with cemented total-joint components. Loosening occurs much more frequently, and sooner, with active

young individuals. Much evidence suggests that loosening is either directly or indirectly related to the use of acrylic bone cement as a grouting agent to secure the implants in the bone. If total joint arthroplasty is to be improved and to be extended to younger, more active patients, it is likely that new prosthesis designs that incorporate porous-ingrowth technology will play a major role.

Ingrowth of the bone into the surface of the implant will result in a very firm fixation and often a continuous, intimate interface that is efficient for stress transfer. However, if such an interface is achieved with current prosthesis designs, the stress fields in the surrounding bone tissue can be radically changed from those in the normal skeleton. In animals, this condition has led to severe remodeling that eventually led to implant failure. More advanced designs are needed that would avoid failures of this type while taking advantage of the potential long service life the porous-ingrowth technique is believed to offer.

The ability to predict the response of cancellous bone to applied stress is critical to the evaluation of porous-ingrowth prosthesis designs. If the bone response to implantation of a new prosthesis can be accurately predicted, the reliability of porous-ingrowth joint prostheses will be greatly improved, and the time required

for design and testing of new design concepts could be dramatically reduced.

Progress—Two-dimensional studies of the normal and prosthetically replaced hip joint have been conducted using nonlinear sliding interface elements at the joint surface. The findings of the normal hip study showed the sensitivity of hip contact pressures and stresses to imposed boundary conditions and indicated that care should be taken to simulate anatomical conditions in experimental and theoretical studies. The study of porous-ingrowth acetabular cups, among other findings, indicated that addition of a flange to the component might result in an improved design.

Three-dimensional studies of an idealized normal femoral head and neck, and of several idealized prosthesis designs using sliding interfaces at the juncture of the bone and metal, have been used successfully to predict the response of cancellous bone to loading. The results of these two- and three-dimensional studies are very encouraging.

Future Plans—More accurate models, incorporating the improvements suggested by the results of these studies, are now under development for future evaluation.

Skeletal Aging and Disease in Failure of Hip Surface Replacement

A.A. Hofmann, Ph.D.; E.P. France, Ph.D.; A.U. Daniels, Ph.D.; N.P. Alazraki, M.D.

Division of Orthopedic Surgery, University of Utah School of Medicine, Salt Lake City, UT 84132

Sponsor: VA Rehabilitation Research and Development Service and Division of Orthopedic Surgery, University of Utah School of Medicine

Purpose—Surface Replacement Hip Arthroplasty (SRHA), in comparison to conventional Total Hip Arthroplasty (THA), has the advantages of replacing the diseased hip surface while preserving normal bone stock, maintaining more normal physiological bone loading patterns, providing an easier method for replacement of failed implants, and decreasing the occurrence of deep infection in the femur subsequent to surgery. However, these advantages have been offset in clinical practice by

high failure rates, mainly due to early loosening of the femoral and/or acetabular components.

The objectives of this project are to determine causes of early loosening in SRHA, and relationships between these causes and skeletal aging and disease. The possible causes for SRHA failure include: 1) poor initial fixation due to inadequate operative technique and instrumentation; 2) bone necrosis secondary to disruption of the blood supply; 3) inadequate

(age/disease-related) initial bone strength; and 4) bone remodeling due to stress redistribution, related either to prosthesis design or to processes of aging and disease.

Preliminary Results—The data obtained from this study will be used to determine the viability of SRHA and, if possible, to design improved components and techniques. The major accomplishments for this study to date are:

1) Three-dimensional mapping of the local trabecular bone mechanical compressive strengths of the femoral head has been completed. The regions of high compressive strength were similar for both healthy and diseased bone and were located in the superior medial portions of the femoral head. The anterior half of the femoral head had a slightly larger compressive strength than the posterior half. A paper with additional information will be submitted for publication to the *VA Journal of Rehabilitation Research and Development (JRRD)*.

2) To assist with the speed and accuracy of histological specimen analysis, a computerized digitization program has been developed.

3) A presentation entitled "Increased Endosteal Bone Loss After Hip Arthroplasty" was given at the 1986 Orthopedic Research Society meeting. The results of this study will be submitted to the *JRRD*.

4) A preliminary study has been completed for radioisotope-based determination of femoral head vascularity in SRHA patients. Technetium-99m (T-99m) HDP- and MDP-based bone-scanning and tissue-scintillation-counting techniques were applied to canines subjected to mock SRHA surgery in order to evaluate the ability of such techniques to measure changes in femoral head vascularity due to surgical stripping of the hip capsule. Results from these studies indicated that for the dog, capsule disruption acutely inhibited blood flow and reduced vascularity by 30 to 70 percent in the surface bone of the femoral head. This study is currently being completed and will be submit-

ted for publication to the *JRRD*.

In addition to the canine studies, the femoral heads and failed prostheses from two consenting SRHA patients were retrieved and analyzed. Both patients had intact femoral and failed acetabular components. Immediately after a normal bone scan, the femoral heads and prostheses were surgically removed, the bone was separated from the prostheses, scanned, and the scintillation counts were compared. The results of these analyses showed that no appreciable differences existed between the proximal and distal portions of the femoral heads after a failure of the SRHA acetabular components. Histological analyses of these acetabular specimens are currently underway.

5) A preliminary study has been initiated to correlate remodeling of bone with prosthesis materials and design. Test cylinders of either porous or smooth cobalt-chrome, titanium, and hydroxyapatite are being implanted into the iliac crests of consenting bilateral total hip patients. After 6 to 8 weeks, these test cylinders are removed with a small portion of attached bone for histomorphometrical analysis of the bone-implant interface.

6) A pilot implant-retrieval study has been initiated to help determine the long-term changes that occur in total joint replacement components and adjacent tissues. The information obtained should be of considerable value in the design of improved prostheses.

Future Plans—Principal project activities for the next few months will include continued collection and processing of specimens and analysis of data for relationships between prosthetic design and bone remodeling. Whenever possible, SRHA patients who suffer from failed prostheses and are scheduled for hip replacement surgery will undergo both histological and scanning analysis. Efforts will be continued to increase the size and effectiveness of the implant-retrieval program to provide more specimens for study.

Photoelastic Investigation of Hip Replacements

John F. Orr, Ph.D.; William V. James, FRCS; Aladdin Bahrani

The Rehabilitation Engineering Center, Musgrave Park Hospital, Belfast, BT97JB, Northern Ireland and Department of Mechanical Engineering, The Queen's University, Belfast, Northern Ireland

Sponsor: *The Department of Mechanical Engineering, The Queen's University, Belfast, Northern Ireland*

Purpose—The effects of forces on models of hip replacements are being investigated by means of photoelasticity. Preliminary studies of the effects of stem cross-sectional profile on bone cement have been reported. The effects of

medio-lateral rotation on stresses in an artificial hip have also been reported. Further investigation is being undertaken on the stresses at the bone/cement and the cement/stem interfaces, using photoelastic analysis.

A New Method of Hip Function Assessment

P.J. Rowe; A.C. Nicol; J.P. Paul; G. Kelly; D.L. Hamblen

Bioengineering Unit, University of Strathclyde; Orthopaedic Surgery, University of Glasgow

Sponsor: *University of Strathclyde*

Progress—It is difficult to measure the success of total joint replacement in restoring function to the arthritic hip. A number of clinical rating scales have been proposed, including the Harris system, but these methods are subjective and intuitive in nature. In order to overcome some of these objections, a new portable microcomputer-based system has been developed and used in a clinical environment to evaluate the hip joint function of total hip replacement patients. Flexion/extension angles are measured for each hip and knee using four flexible electrogoniometers. The temporal parameters of gait are recorded using foot switches, and supportive forces are measured using instrumented walking aids. The instruments are linked to the microcomputer using a long trailing cable.

plications or pain, 60 percent of normal hip motion is restored 6 weeks postoperatively. This improvement continues with typically 75 percent of normal motion being obtained after 6 months and 80 percent after 12 months. There is a decrease in compensatory movements leading to an increase in walking velocity, step symmetry, and efficiency.

Comparisons have been made between these results and the Harris index and full biomechanical analyses, and it is suggested that the system provides a more accurate assessment of hip function than conventional clinical indices.

Future Plans—Future work will involve a full-scale clinical trial. Sixty patients will be examined prior to and at intervals following surgery, and the clinical significance of the results will be determined.

Preliminary Results—The results showed that provided there are no major postoperative com-

Total Hip Biotelemetry

John R. Moreland, M.D. and J. Michael Kabo, Ph.D.

Wadsworth Veterans Administration Medical Center, Los Angeles, CA 90073

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The objective of this project is the design and development of a special total hip femoral component that contains within it a miniaturized biotelemetry system capable of

broadcasting signals received from strain gauges mounted inside the neck of the prosthesis. The prosthesis will be inductively powered by an external coil that is positioned in the vi-

cinity of the prosthesis tip, thus eliminating the need for internal batteries or connecting cables. This is a collaborative effort involving the Research Service of the Wadsworth VA Medical Center, the UCLA Division of Orthopaedics/Biomechanics Research Section, and the Jet Propulsion Laboratory (JPL).

Progress—Since the last report, the contracts and funding for the program have expired. The following represents the items that have been completed:

Of the original six partially machined prosthesis housings, two have been completed and instrumented with the full complement of strain gauges and electronic assemblies. One additional unit is fully strain gauged but has not been fitted with the electronic subassemblies. Four additional sets of electronic subassemblies have been manufactured and tested under accelerated life testing but have not been incorporated into the prosthesis housings. These completed devices as well as the power induction system, the electronic receiver/antenna system and additional subassemblies have been delivered by JPL. Failure of a single gauge element was detected during final electronic testing of one of the fully instrumented

devices. The cause of the failure has not been determined, but it is believed to be irreparable. This unit will be used for mechanical *in vitro* tests and development of the data-processing aspects of the program.

Future Plans—Several tasks remain to be completed. The two functional units will be loaded mechanically to ensure sufficient gauge sensitivity and to perform direct mechanical calibration of the output. Depending on the outcome of the tests, these units may be returned to JPL for modification of the internal gain settings to maximize the signal-to-noise ratio. Next, the femoral cap will be E-beam welded to the units, and the hermeticity of the units verified. Final machining will be conducted on these units and the integrity of the electronics verified. The unit with a single channel failure will be subjected to a mechanical test program under a variety of loading conditions that will be used for development of the data recovery aspects of the program. Upon completion of these tasks and in the absence of significant problems, all data will be submitted to the appropriate Human Use Committees for approval for *in vivo* implantation of the fully functional device.

C. Knee

Investigation of a Simplified Internal Knee Prosthesis

Peter S. Walker, Ph.D.; Thomas Cochran, M.D.; Joshua Rovick; Frederick Ewald
Veterans Administration Medical Center, West Roxbury, MA 02132

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This study proceeded on a number of fronts to facilitate the design and evaluation of a Press-fit total knee. The data were applied to a design that was produced in limited quantity by a major manufacturer and tested clinically in patients under an IRB procedure. Lack of FDA approval has prevented further clinical expansion at this time, but this has been planned.

Progress—Seventeen Press-fit uncemented total knee replacements were reviewed at 6 months to 2 years to determine if this was a viable alternative to conventionally cemented total knee replacement. Indications for the procedure were youth, postsepsis, requiring bone graft, and overweight and/or high-demand patients. Results showed good pain relief and independent ambulation at 3 months postopera-

tive with an average range of motion of (-) 0.7 degree extension (0 degree to -5 degrees) and 100 degrees flexion (80 degrees to 117 degrees). There were no significant complications. Conclusions are that there are no important differences between Press-fit and cemented knee arthroplasty regarding pain relief, time on crutches, function, blood loss, or operating time.

Optimum Design—Since the time of the clinical evaluations, the design of the prosthesis has been refined.

In the design of condylar surfaces for TKR, there are several conflicting requirements. Normal knee motion involves 15 degrees of tibial rotation and 8 mm of rollback, from 0 to 120 degrees flexion; about any position, there is 20 to 30 degrees and 5 to 10 mm of laxity; uncertainty of component placement at surgery might require additional laxity. These factors suggest that low-constraint tibial surfaces are needed. One advantage is the low shear and torque forces transmitted to the interface. However, the surfaces will be more unstable than normal, placing undue reliance on the remaining soft tissues. Low conformity gives high contact stresses on the plastic, which could lead to catastrophic material breakdown in the long term. We measured contact stresses of current TKRs. We then computer-generated tibial surfaces with different motion-laxity-stability criteria and calculated the contact stresses in an attempt to determine the most acceptable geometry from all aspects.

The contact area and stresses in current TKRs were determined at 0 degrees and 60 degrees flexion by placing Fujifilm between the surfaces and loading to 1500 N. The prostheses evaluated were Cloutier, I-B, RMC, PCA, Kinematic Condylar, Kin Total Condylar, and Microlok.

The starting point was to determine average femoral surface geometry by slicing 23 knees and 25 sections, digitizing, and averaging. The surfaces were represented by a piecewise mathematical analog of spherical, toroidal, and conical surfaces. Average knee motion was determined by flexing and extending 23 knees dynamically under quadriceps action. Interior-exterior rotation and anterior-posterior displace-

ment were expressed as a function of flexion: $Y = BX + CX^2 + DX^3$ (X = flexion). Equations for laxity curves of intact knees, were similarly expressed. To reproduce laxity with the TKR, the criterion was that the surfaces alone would provide the same laxity curves as the intact knee. The theory was based on energy considerations. For example, for a-p motion, the laxity equation was $S = f(X)$. The motion of the femur on the tibial surface is given by $Y = 1/p \int f(X).dx$. (S = shearforce or torque, X = horizontal displacement or rotation, p = compressive load). This equation defined the vertical height of the femoral surface as a function of a-p displacement. Similar equations were derived for interior-exterior rotation and medial-lateral displacement. The expressions were obtained for all flexion angles. To generate a tibial surface, the femoral surface was moved in the computer through a prescribed path of motion and/or laxity in multiple discrete steps. A horizontal gridwork was defined on the tibial surface, and the lowest Y -values at each node were collected to define the tibial surface. The femur was then placed through its original motion path. The contact points were determined, and the local radii of curvature along a-p and m-l axes calculated. Using elasticity theory, the contact areas and maximum compressive stresses were calculated ($E_{\text{plastic}} = 600 \text{ MPa}$).

Results—The maximum compressive stresses (1.5 x average) for total joints exceeded the maximum strength (15 MPa) by 3 to 7 times in flexion. Even in extension, with more conformity, the values were from 1.9 to 6 times. The high stresses occurred even for "line-contact" of a cylinder on a flat. The computer-generated tibial surfaces gave a range of stresses depending on the input motion and laxity. The least stresses occurred when the femoral component was moved uniaxially—a maximally constrained condylar knee. A cylinder-on-flat gave moderately high stresses on lateral and medial sides. The highest stresses were with the biconvex femoral condyles on a flat surface. For a laxity-only surface, stresses in the full range were moderate. For average knee motion, the lateral stresses were high due to the flat "roll-

back" area. With average knee motion and laxity combined, the stresses were similar to average knee motion. Halving the anterior-posterior motion and interior-exterior rotation, and making the laxity twice as stiff as normal, resulted in moderate stresses.

All geometrics produced stresses that were higher than the compressive strength of the plastic. Geometries that allow free anterior-posterior motion by flat tibial surfaces have both

high stresses and excessive laxity. For uniaxial motion, the stresses were much lower, but at the expense of laxity. "Laxity only" surfaces gave only slightly higher stresses. A reasonable compromise was to reduce the freedom of motion in anterior-posterior and rotation as prescribed by normal knee motion and instead to build in this motion in the form of laxity, which resulted in more curved surfaces with reduced stresses.

Stiffness and Porosity of Cancellous Bone from Total Knee Patients

Richard L. Wixson, M.D.; Neal Elasky, B.S.; Jack L. Lewis, Ph.D.
Northwestern University, Chicago, IL 60611

Sponsor: *National Institute of Handicapped Research*

Purpose—This project is a continuation of a project originally funded by the Multipurpose Arthritis Center of Northwestern University. The objective was to measure the stiffness of cancellous bone plugs taken from patients undergoing total joint replacement and to compare this with published values for normals.

Progress—During the current report period, several additional specimens were tested, bringing the total to 132 specimens, and the data analyzed. For each specimen, Young's Modulus, ultimate stress, and area fraction of bone were

measured. Patient age, sex, weight, disease, and joint deformity were recorded as well. Careful statistical analysis showed no correlation of area fraction with any of the recorded variables. Stiffness and strength were highly correlated, with a significant difference between osteoarthritic and rheumatoid bone. Stiffness of all of the patient bone was either equal to or less than normal bone stiffness, except that bone from the lateral side of valgus knees was above normal. These data are still being analyzed, and a paper reporting the results is being prepared.

Synatomic Knee Clinical Investigation

Edward E. Kimbrough, M.D. and Edward Berg, M.D.
USC School of Medicine, Columbia, SC 29203

Sponsor: *DePuy, P.O. Box 988, Warsaw, IN 46580*

Purpose—This project is designed to obtain sufficient clinical data for a premarket approval application to the FDA for approval of the Synatomic Knee Porous Coated Noncemented Replacement. The sponsor has approval to admit up to 200 subjects into this clinical investigation, with 120 subjects entered at this date. It is expected that a study population of 500 subjects will be required for sufficient clinical data to meet the goal of this project.

Progress—It is believed from the data compiled from the 120 cases entered into the clinical investigation to date that the porocoat synatomic knee appears to be a safe and effective prosthesis when utilized under the guidelines set forth in the study protocol. The risks associated with this device appear to be no greater than those risks associated with a cemented knee arthroplasty.

Design Concepts for a Porous-Ingrowth, Prosthetic Tibial Component

Gary Beaupre, Ph.D., and Dennis Carter, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—In 1976 it is estimated that 40,000 total knee replacements were performed in the United States alone. With improvement in designs and techniques, it can only be estimated that many more replacements are being performed today. In spite of this fact, the rate of long-term success, especially in young, active patients, is alarmingly low. The most frequent cause of failure is tibial component loosening. Most evidence points to the fact that loosening is either directly or indirectly related to the use of polymethylmethacrylate cement as a grouting agent to secure the implant to the bone.

Progress—In recent years much effort has gone into research aimed at developing techniques and designs that would eliminate the use of acrylic bone cement. It is now being recognized that cementless fixation (e.g. using porous ingrowth technology) of artificial joint components is one of the most challenging and potentially rewarding areas of research in orthopaedic surgery today. In spite of this, there is a paucity of studies which carefully and critically assess various cementless, prosthetic designs in a quantitative manner. Our goals are to evaluate present tibial component designs and to make modifications resulting in new designs having improved expected lifetimes.

Since total joint replacement primarily affects the aged, it is important to note that there are presently about 5 million veterans of age 65 and older. It is estimated that by the year 1990 more than half of all American men of age 65 and over will be veterans. From these statistics it is clear that the veteran population will be a significant beneficiary of improvements in total joint design.

A technique that has been immensely successful in recent years in the design process of prosthetic joint components is the Finite Element Method (FEM). The FEM for both allows

the bone and the prosthesis to be modeled mathematically and enables the designer to compare different designs quantitatively. Stress distributions within the bone surrounding the prosthesis can easily be compared to the stress distributions which exist within the normal joint. Areas of bone which are likely to fail can be pointed out and designs can be modified in order to alleviate these potential failures.

It is believed that the optimum prosthetic design is one in which the internal bone stresses are distributed similarly to those in the non-prosthetic joint. When such designs are used, extensive bone remodeling can be avoided, resulting in improved expected lifetimes.

Results—Cadaver tibiae are sliced in order to obtain bone geometry and material properties. A finite element mesh is then generated and anatomic loading and boundary conditions are applied. Both frontal and sagittal plane models are created. The results of the anatomic or non-prosthetic tibia are compared with a number of different prosthetic designs. Several types of finite element models are going to be studied, including: two-dimensional equivalent thickness models, two-dimensional non-linear contact models, and full three-dimensional models.

Linear, two-dimensional, equivalent-thickness models have been completed.

Results indicate that conventional prosthetic designs with large posts or multiple pegs lead to non-physiologic stress distributions which predispose the implant/bone interface to failure. A new implant whose design is based upon the internal architecture of the tibia presents a more benign stress distribution implying less extensive bone remodeling. Non-linear models are now under development to see if this new design also performs better in the immediate post-operative stage (before bony ingrowth occurs) when the effects of the lack of a grouting agent will be most pronounced.

D. Other

Evaluation of Elbow Joint Function Post-Elbow Joint Arthroplasty

K.D. Beveridge, MSc.; A.C. Nicol, Ph.D.; W.A. Souter, FRCS

Bioengineering Unit, University of Strathclyde and Princess Margaret Rose Hospital, Edinburgh, Scotland

Sponsor: *The Arthritis and Rheumatism Council*

Purpose—Improvement of function is of primary concern in the treatment of the rheumatoid elbow joint by surgical means. In 1977 the first Souter-Strathclyde elbow joint replacement was inserted into a patient. To date 135 prostheses have been implanted, and of the groups assessed for a period of 2 to 5 years the postoperative results have been encouraging. However, it has been recognized that present clinical methods of evaluating the success of the arthroplasty postoperatively do not measure the overall performance of the elbow joint as an objective measurement of what the patient actually does in his own home or work.

Progress—A system to investigate elbow joint usage while the subject is unsupervised in his own environment has been developed. The system involves fitting both elbows of the subject with strain-gauge electrogoniometers and collecting the data in a portable cassette recorder for later evaluation.

Preliminary Results—Results from preliminary investigations on 15 observed subjects performing selected functional activities including dressing, reading, and domestic tasks showed that individual activities could not be identified by individual patterns of motion obtained from the recording of the subject. On subsequent longer tests on unsupervised subjects it was found that elbow joint function could be defined in terms of: 1) patterns of motion; 2) range of movement; 3) amplitude of motion; 4) frequency of motion; and 5) summation of motion.

Further methods of analyzing the data are presently being investigated.

Future Plans—Over the next 3 years the above system will be used in an investigation of the postoperative performance of the elbow joint following insertion of the Souter-Strathclyde elbow prosthesis. Patients will be monitored prior to their joint replacement and then postoperatively at 1-, 3-, 6-, and 12-month intervals. To overcome day to day variability, three separate recordings will be made at each interval. Each patient will be fitted with the equipment in the morning of the test and at their own homes. The recorder will run continuously until the following morning, when the researcher will again visit the patient's home and either refit the equipment for a further recording or collect the equipment. A control group will be set up similar in age, sex, occupation, and in other characteristics.

As a result of the intended investigation, it is hoped that the following information will be provided: 1) the frequency, motion type and range of movement of the elbow joint utilized by patients suffering from rheumatoid arthritis of the elbow prior to surgical replacement of the diseased joint; 2) the corresponding information relating to the elbow joint postoperatively following surgical replacement; 3) the progress of joint performance measure in this way at regular intervals postoperatively; and 4) a comparison of patient elbow function with that of normal individuals.

Stress Analysis for the Normal and Prosthetic Shoulder

Dennis Carter, Ph.D. and Tracy Orr, M.E.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94303

Sponsor: VA Rehabilitation Research and Development Service

Purpose—For patients with arthritis and other crippling diseases, the total joint replacement has become a standard procedure to relieve pain and increase mobility. A new area of orthopaedics is the use of porous-coated prosthesis to secure the implant in the surrounding bone. The successful ingrowth of bone into the implant surface could result in firm fixation and a continuous interface which would be efficient in stress transfer. The two important aspects in using these devices are the initial control of the bony ingrowth, and the effects of bone remodeling due to changes in the stress fields.

It is important to achieve implant stability over a range of loading conditions, and to avoid shear and tensile loading at the prosthesis/bone interface. The stress fields in the surrounding bone tissue can be radically changed from those in the normal skeleton upon the implantation of a device which allows porous-ingrowth components. This has resulted in extreme bone remodelling and eventual implant failure in experimental animal models. Bone remodels to the extent that it can no longer support the implant. The supporting bone fractures and the interface bonding is destroyed.

Because of the importance of bone remodeling with the use of porous-ingrowth implants, the question has arisen of where to apply the porous coating so as to achieve its theoretical potential benefits.

The purpose of this study is to more fully understand the biomechanics of the shoulder joint and to analyze various prosthetic designs. Although there have been few reported clinical problems on the humerus surface, long-term results are not in. On the glenoid surface, there have been several cases of clinical loosening, and evidence (shown by a large number of radiolucent lines on X-rays) that loosening may become a serious problem in the future of total shoulder arthroplasty. Determining the underlying concepts behind an optimum design could

lead to the shoulder replacement procedure being performed more often, lasting longer, and having little need for revision surgery.

In the approach adopted, cadaver humera and scapulae are sliced in order to obtain bone geometry and material properties. A finite element mesh is generated and anatomic loading and boundary conditions are applied to the model. The results of the anatomic humerus and glenoid are compared with a number of different prosthetic designs. Several types of finite element models can be used: plane stress, equivalent thickness, axisymmetric and nonlinear contact, and three-dimensional analysis.

Progress—Finite element analyses have been performed on both the humerus and the glenoid. The humerus model was analyzed using both a plane stress model and an equivalent thickness model. The principal stresses and von Mises' stress contours were determined for the normal humerus, and for three different prosthetic humeral head designs. Each prosthetic design was modeled to have a totally porous-coated surface, and a surface which was porous-coated underneath the femoral head. Three loading cases were used for each model.

The stresses in the bone at the prosthesis/bone interface were examined underneath the humeral head to determine which prosthetic design resulted in principal stresses at the interface, with the minimum of shear stresses. The glenoid side was modeled using a uniform thickness and plane stress analysis (a uniform thickness model was not appropriate for the glenoid side). Various design parameters were examined for the prosthetic models, including flange design, metal-backing of components, and superior constrained designs. A continuous, rigid prosthesis/bone interface which would be achieved by bony-ingrowth devices was assumed. Principal stresses and maximum normal stress contours were determined for

each of the prosthetic models.

Future Plans—The next step in determining the best design to prevent glenoid component

loosening will be the analysis of an axisymmetric glenoid model with the ability to apply both axisymmetric loads and non-axisymmetric loads.

Design of a Two-Component Finger Prosthesis

Robert Whalen, M.S. and Robert Chase, M.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94303

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Approximately six percent of the population suffers from the disabling effects of arthritis of the hand. Rheumatoid arthritis accounts for the overwhelming majority of these cases. Destruction of the ligamentous structure and surrounding soft tissue and erosion of the articular surfaces cause pain and loss of function. Disruption of the delicate balance between the active muscle forces and the passive restraining forces of the soft tissues and articular surfaces results in eventual deformity.

The goal of this project is to design and develop a two-component metacarpophalangeal (MCP) prosthesis which restores function and strength to the joint. The MCP joint is considered the master joint of the hand and has been the focus for the majority of research efforts.

Finger implants have undergone three significant developments. The first prosthesis implanted was a double-stemmed metallic hinge. Although overall hand function improved initially, overconstrained joint rotation caused stem fractures and stem migration. As opposed to the first designs which were highly constrained, the second generation of prostheses functioned more as soft, flexible spacers. These have performed well in correcting deformity and eliminating pain, but they are incapable of returning the finger joint to full range of motion and strength. The impressive successes of total hip replacements have launched the current third generation of designs. We believe that a properly designed two-component system

offers the best chance for success.

A reliable finger implant must address the problems of stem fixation, joint stability, and joint range-of-motion. We hypothesize that these criteria are best met with a two-component system that incorporates a more anatomical articulating surface geometry with bone or fibrous tissue ingrowth for stem fixation.

Progress—We have developed the capability to fabricate precision prototypes and we are currently concentrating on several articular surface geometry configurations. These will be implanted into cadavers to test for adequate range of motion and stability.

Design ideas for stem fixation are proceeding independently, and will eventually be combined with the appropriate articular surface for additional cadaver experiments.

Future Plans—The development of the finger prosthesis has been divided into five stages. Stage I involves the design and development of prototypes. Implantations of prostheses into cadavers in Stage II will overlap with Stage I to insure functional designs. These designs will be mechanically tested and compared to existing commercial implants in Stage III. Successful units will then be implanted into rabbit knees (Stage IV). If we achieve our expected results, we will initiate human implant studies in Stage V.

IV. Spinal Cord Injury

A. General

The Use of EMG Biofeedback and Functional Electrical Stimulation in Spinal Cord Injury

Barth A. Green, M.D.; Bernard S. Brucker, Ph.D.; Dorthea Glass, M.D.; D. R. Ayyar, M.D.; Marilyn S. Wells, M.D.; Christy L. Holmok, M.S.

Miami Veterans Administration Medical Center and University of Miami School of Medicine, Department of Neurological Surgery, Miami, FL 33136

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This project investigates the relative effectiveness of computerized electromyographic (EMG) biofeedback, functional electrical stimulation, and physical and occupational therapy in various combinations for the purpose of restoring function in persons with long-term spinal cord injury.

The project is based on previous research from our laboratories using a sophisticated form of computerized EMG biofeedback as a specific operant conditioning procedure for establishing more efficient use of the nervous system, specifically the spinal cord, in persons with long-term spinal cord injury.

The results of this previous work had suggested three very important phenomena: 1) for people with cervical spinal cord injuries it is possible that neural repair can take place over periods of time longer than 6 months or 1 year; 2) the brain is not efficient at utilizing these repaired neurons in the spinal cord; and 3) existing alternate pathways from the brain to extremity muscles in quadriplegics are viable but not functional prior to biofeedback identification and utilization. Furthermore, it appears that specific training using operant conditioning methods with advanced computerized biofeedback technology could increase the brain's efficiency in utilizing these neurons resulting in greater voluntary motor neuron control over paretic muscles. In addition, our research with functional electrical stimulation had indicated that in cases where there has been significant

atrophy to muscle tissue, computerized functional electrical stimulation could restore these muscles. It had also appeared that some of these late spinal cord injury cases had the potential for regaining function with physical and occupational therapy techniques.

Progress—The present study was designed to test the relative effectiveness of EMG biofeedback, functional electrical stimulation (FES), and physical and occupational therapy (PT and OT) in specific combinations for the purpose of restoring function in long-term spinal cord injured people. Eighty persons with spinal cord injuries at level C3 through C7 with resulting quadriplegia are matched according to level of injury, muscle strength, EMG recruitment, and activities of daily living, then randomly assigned to one of four groups: 1) EMG Biofeedback-FES; 2) EMG Biofeedback-OT, PT; 3) FES-OT, PT; and 4) OT, PT-OT, PT.

Eight weeks of each treatment modality are provided two to three times per week in sequence. Measurements of muscle strength, EMG recruitment, an EMG test utilizing needle electrodes, active and passive range of motion, and functional performance in activities of daily living are taken prior to the start of the experiment, after each treatment segment, and at the 6-month followup.

EMG recruitment is measured by a specially designed multiprocessor computer system. This unit also provides the EMG biofeedback on

several muscle sites simultaneously according to preestablished operant conditioning procedures. Passive and active range of motion is measured with goniometers and standard testing procedures. Functional activities of daily living are assessed by instruments specifically designed for this study. The OT and PT treatments are provided by therapists with expertise in spinal cord injury according to standard treatment protocols for increasing function. FES is provided by a computerized system according to preestablished protocols.

Currently, persons with chronic cervical level spinal cord injuries are participating in all phases of the project, from initial screening

through the therapeutic modalities and clinical treatments.

Future Plans—The implications of this study could be wide ranging, considering the current theory underlying the treatment of the spinal cord injured, which obviates providing rehabilitation to the long-term paralysis victim. In addition, the study will identify the relative contributions of biofeedback, functional electrical stimulation, occupational and physical therapy, and will determine the most effective combination of these for restoring function in long-term spinal cord injury.

Microwave Myelography: A Feasibility Analysis

Scott R. Crowgey, M.D., and Steve Sharpe, Ph.D.

Veterans Administration Medical Center, Decatur, GA 30033

Sponsor: VA Rehabilitation Research and Development Service

Purpose—A means for noninvasively imaging the spinal cord and subarachnoid space would be a marked improvement over the currently used invasive forms of myelography for the evaluation and followup of spinal cord injuries resulting from trauma or degenerative disease. Although the bony protection provided by the vertebrae prohibits the use of X-rays or ultrasound for this type of imaging, the intervening bone would not be as great a barrier to the use of microwaves in this region of the body.

Future Plans—This project will evaluate the feasibility of using both wide-band continuous-wave techniques and impedance-sensitive re-

flection techniques for the two-dimensional microwave mapping of the spinal subarachnoid space. This investigation will primarily involve the analysis of relevant literature based on the results of a literature search and a patent search. Based on this initial analysis, an experimental protocol will be developed to further establish the feasibility of this approach for application to noninvasive myelography. It is anticipated that these efforts will then serve as a basis for the preparation of a larger proposal for a study that will better support the investigational equipment and time required for completed evaluation.

Corticospinal Systems

Peter L. Strick, Ph.D.

The Research Foundation of the State University of New York, Syracuse, NY 13210

Sponsor: Paralyzed Veterans of America Spinal Cord Research Foundation and the National Spinal Cord Injury Association

Purpose—Interruption of the corticospinal tract, the major pathway descending from the cerebral cortex to the spinal cord, results in immediate loss of skilled movement. Although

some recovery of motor function is possible after corticospinal lesions, hand movements are permanently impaired. For that reason this pathway has long been recognized as an impor-

tant motor pathway for generation and control of forelimb movements.

Progress—Preliminary studies suggest that 1) the corticospinal tract originates from wider areas of the cerebral cortex than previously recognized, an observation that is relevant to patients with motor difficulties after spinal cord injury, and 2) a special component of the corticospinal tract terminates only in upper segments of the cervical spinal cord.

Preliminary Results—This research is designed to confirm and expand these observations, which have important clinical implications. Severe neck injuries often damage lower segments of the cervical spinal cord and result in

paralysis of hand and lower body movements. This type of injury interrupts many long descending pathways as well as short pathways that interconnect spinal cord segments. Early results suggest that the component of the corticospinal pathway that terminates in upper segments of the cervical cord is not damaged by most neck injuries. Thus, this pathway could provide normal signals for the control of paralyzed limbs.

Future Plans—In the future, after these studies have provided the crucial basic information of the corticospinal tract, one might attempt to restore hand function with, for example, nerve bridges that cross the injury site.

Role of Intrinsic Motoneuron Properties in Abnormal Rate Regulation After Spinal Injury

W. Zev Rymer, M.D., Ph.D.

Northwestern University, Chicago, IL 60611

Sponsor: Paralyzed Veterans of America Spinal Cord Research Foundation

Purpose—Incomplete spinal cord injury often produces weakness of voluntary muscle contraction below the site of the lesion, a weakness usually attributed to a loss of descending excitatory input to those neurons responsible for activating the muscles, namely, the motoneurons. As a result, fewer motoneurons can be voluntarily activated and those that can be activated are not driven maximally. Previous work has demonstrated that even over the range that motoneurons are activated, their patterns of activation are abnormal so that muscle tension is produced inefficiently; in an animal model of spinal cord injury, evidence was strong that motoneuron response properties are altered by spinal lesions.

In the new research the nature and mechanism of this alteration of motoneuron discharge properties will be investigated.

Progress—Research is proceeding according to plan, although some of the experiments proved more difficult than had been expected. During the first 6 months, work focused on the charac-

terization of motor unit discharge patterns, and the related disturbances of EMG and force production after surgical lesions of dorsolateral spinal white matter. Twenty preparations have been studied, 13 of which were used for motor output studies and 7 for studies of afferent mechanisms.

Work has begun on the effects of contraction-induced receptor discharge in spinal motor output after lesions of dorsolateral spinal white matter. In five cats, fatigued MG muscle induced more powerful inhibition of synergistic muscles than did unfatigued muscles; this inhibition is more potent when it follows a dorsolateral quadrant spinal lesion. This must be confirmed by additional preparation.

Future Plans—Further clarification of the importance of the motor unit type will be by application of new methods that are being developed. Inasmuch as only one to three axons can be followed in any one animal, it will require greater effort to accumulate an adequate sample.

An Implantable Sensor for Two-Degree-of-Freedom Position Transduction

P. Hunter Peckham, Ph.D.

Case Western Reserve University, Cleveland, OH 44106

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation and the National Spinal Cord Injury Association*

Purpose—The investigators will design, develop, and evaluate a permanently implantable device to provide two independent control signals for use as a command control and feedback source in upper extremity assistive systems for high-level spinal cord injuries.

The implanted device will measure relative skeletal position changes of opposing bony segments. Movement will be generated by voluntary movement of that part of the body over which the user retains voluntary control. This

information will allow the user to control hand positions and force a functional neuromuscular stimulation (FNS) hand assist system (e.g., in C4 injury or lower, the shoulder; in C6 or lower, the wrist).

Alternatively, the system may be used in a position feedback loop, such as for control of wrist position by FNS in a C5-level quadriplegic patient. The implanted devices can also be used to control upper extremity prostheses and powered wheelchairs.

Trial of a 5-Lipoxygenase Inhibitor in Experimental Spinal Cord Injury

Lloyd A. Horrocks, Ph.D.

The Ohio State University, Columbus, OH 43210

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation and the National Spinal Cord Injury Association*

Purpose—It appears that shortly after spinal cord injury, cholesterol and certain phospholipids begin to break down, which compromises the ability of the cell membrane to act as a selective barrier. Moreover, certain products of the phospholipids are converted into potent compounds (prostaglandins and leukotrienes) that greatly reduce blood flow to the injured area and cause the injured segment to swell and become inflamed.

These early biochemical changes and subsequent pathological events (ischemia, edema, and inflammation) seem to contribute significantly to the nerve damage that results from

severe injury to the spinal cord. This secondary injury can be treated by drugs, providing that all the attendant pathological events are fully understood.

This research is to examine the breakdown of these membrane phospholipids and the production of prostaglandins and leukotrienes using an experimental model of spinal cord injury compression of the spinal cord of a cat.

The second part of the study is to test the ability of a new powerful inhibitor of leukotriene production (L652, 343) to prevent the formation of these compounds after injury to the spinal cord.

Circulation and Metabolism in the Decentralized Spinal Cord

Oscar U. Scremin, M.D., Ph.D.

Veterans Administration Medical Center, Albuquerque, NM 87108

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation*

Purpose—This research is designed to describe the degrees of adjustment between metabolic needs and blood supply in sensory and motor

centers of the spinal cord in the absence or presence of a complete transection, and to determine how this adjustment is maintained in

situations in which complications such as spasticity and autonomic disreflexia are present. In addition, we will establish which areas in the spinal cord become metabolically hyperactive when such complications develop.

Progress—To date the researchers have found correlations between spinal cord energy metabolism, a direct index of neuronal activity, and motor behavior in paraplegic rats. This phenomenon is now being studied in greater depth

with the hope that it will provide better insight into the mechanisms of spasticity.

Preliminary Results—A more detailed quantitative analysis of limb movement in the spinal cord of injured rats was added to the study, as well as a study of metabolism in the paraplegic rat. Preliminary results have been most interesting, but the researchers report that it is too soon to make a definitive statement about these early findings.

Retrospective Analysis of the National Spinal Cord Injury Care System Database _____

P. R. Fine, Ph.D. and Michael J. DeVivo, Ph.D.

University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute of Handicapped Research*

Purpose—Systematic and comprehensive management of acute spinal cord injury (SCI) is directed towards reducing morbidity and mortality, increasing life function capacity, and minimizing costs of care associated with this catastrophic condition. Accordingly, it is desirable to establish a mechanism to evaluate performance of the organized management system addressing desired outcomes in such a way that the impact of the system compared to other presystem or parallel nonsystem activities is clear.

Furthermore, assessment of system performance over time is essential to establish patterns of behavior which may then serve as a basis for implementing practice, policy, or programmatic change(s), if necessary.

This study is evaluating, retrospectively, the performance of the Model Regional Spinal Cord Injury Care System, emphasizing quantifiable outcome variables.

Progress—Overall system performance is being evaluated using appropriate statistical procedures. The evaluation methodology includes, but is not restricted to: 1) the relative proportion of all new SCIs brought into and managed by federally sponsored model systems in a given year (i.e., national capture); 2) average time between injury and system admission (i.e., mean time into system); 3) post-admission death

rate (i.e., mortality); 4) post-admission medical complication and surgical procedure rate (i.e., morbidity); 5) level of post-discharge independence, place of post-discharge residence, vocational outcome (i.e., life function); 6) post-injury hospitalization experience (i.e., length-of-stay and re-admission experience); and 7) costs characterized on the basis of appropriate epidemiologic variables to facilitate comparisons between early admission and delayed admission patients.

Preliminary Results—Data indicate that day one admissions have substantially shorter acute care lengths of stay. Overall lengths-of-stay are also substantially lowered in day one admissions. The mortality experience of system patients is markedly lower than that reported by others. Specific epidemiologic and demographic characteristics of patients admitted to the system are available in a recently published book, *Spinal Cord Injury: The Facts and Figures*, available from the National Spinal Cord Injury Statistical Center.

Future Plans—In the coming year we will conduct research on the sponsors of SCI hospitalization expenses and post-discharge care and their relationships, if any, to outcome variables. In addition, we plan to examine the effects of aging on spinal cord injury.

Devices to Assist Transport, Diagnosis, and Treatment of Acute Spinal Injury Patients

Eric E. Sabelman, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service, and Paralyzed Veterans of America

Purpose—This project is part of a program to improve treatment of spinal cord injury (SCI) patients during the earliest phase of rehabilitation—from the time that SCI is diagnosed in a hospital emergency room, through transport to a specialized spinal center, and whenever the patient must be moved under traction for therapeutic or diagnostic procedures such as computerized tomography (CT) or magnetic resonance imaging (MRI).

Apparatus for moving an acute SCI patient must satisfy the size, strength, and weight constraints of helicopter transport, and the need for X-ray transparency without compromising stability of the spine. There is evidence that at least part of the neurological deficit accompanying SCI is due to factors other than the initial trauma, such as continuing compression of the spinal cord by displaced vertebrae and progressive edema.

It is imperative to begin fracture reduction as early as possible after injury and to maintain it uninterrupted during transport. Furthermore, if appropriate therapies to ameliorate neurological damage were to become known, treatment could be begun during transport before the onset of irreversible deficit.

Equipment for moving patients in traction existed previously, but it was often inaccurate, sensitive to acceleration, and poorly adapted to the newer helicopters being employed to good effect in transporting acute patients. After admission to a spinal care center, the patient is commonly placed on a turning frame or kinetic bed to assist respiration and minimize pressure sores. This apparatus frequently does not succeed in eliminating adverse vascular, respiratory and skin effects and entails lifting the patient whenever he/she is moved for further treatment.

Progress—Constant-force traction was provided by a prototype laminated-wood backboard deliv-

ered to Santa Clara Valley Medical Center (SCVMC) for trial in 1980. A second design was developed in 1982 using different criteria which emphasized manufacturing techniques.

The current series of transport backboards are made of orthogonal carbon-fiber/epoxy skins over a curved foam core. Bending tests demonstrated stiffness equal to a flat steel plate of the same thickness. The traction device has nine cables each producing a nominal tension of 2.6 pounds; internally, two constant-force springs apply torque to a common output spool, on which 18 inches of cable are wrapped. Unacceptable friction (greater than 0.5 lb) in the first model was corrected, but a modification of an earlier design having a single spool with extension limited to 6 inches should yield smoother force output at less cost.

Because stainless-steel skeletal fixation devices interfere with radiography of potential head injuries, they are to be replaced with a carbon-fiber halo or tongs. Although much lighter than stainless steel, the composite matrix requires a larger diameter plastic outer screw with a metal core of minimum X-ray cross-section. The tongs have integral keyholes for attachment of traction cables, reducing weight and length. A lateral head-restraint having motion constrained to be parallel to the backboard axis can be retrofitted on the backboards.

Integration of the backboard with long-term patient support is to be accomplished by enclosing the patient and backboard in a sectional cylinder which can be rotated. Rotation may be either periodically, as a turning frame, or continuously, as a kinetic bed, with the patient in prone, supine, or lateral position. Accelerometers and load cells are used to measure actual forces transmitted to the patient. Unused cylinder sections are held by a separate crane.

A grant from the Paralyzed Veterans of

America has supported the fabrication and delivery for clinical trial of six carbon-fiber/epoxy backboards with improved constant-force traction devices. Arrangements have been made to commercially produce small lots of additional backboards for expanded trials. Several carbon-fiber/epoxy halos and tongs were made and laboratory tested; the tong design is a good candidate for mass production. The cable-output traction device is clinically usable, but the proposed third design iteration may result in a simpler, semidisposable product.

New backboard/traction systems have been in use by SCVMC and by the "Life-Flight" helicopter group at Stanford University since February, 1985. During the following 8 months,

SCVMC's Department of Rehabilitation and Physical Medicine had 47 acute SCI patients (admitted less than 7 days after injury). Of the 27 cervical injuries, all but two were placed on the backboard for CT scanning (exceptions had early halo/vest stabilization).

The Life-Flight team transported more than 40 SCI patients (lower spine as well as cervical) and occasionally used the backboard for other injuries, specifically arm and multiple trauma.

In January 1986, another backboard/traction set was placed with Rancho Los Amigos Hospital, for use by the UCLA-"MedStar" helicopter. An instructional videotape has been prepared for training of such multicenter users.

Documenting and Utilizing Programs that Provide Community Adjustment and Independent Living Services for Persons with Spinal Cord Injury

Margaret A. Nosek, Ph.D.

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *National Institute of Handicapped Research*

Purpose—The purpose of this project is to collect and maintain information about independent living and community adjustment programs that serve spinal cord injured people, to provide an effective means of communicating new ideas and experiences among individuals operating these programs, and to provide access to a dependable source of technical assistance related to these programs.

Progress—Nonexperimental survey methodology is being used. The data from earlier administrations of this survey were summarized in frequencies according to specified categories of interest, and some correlation studies were done to determine trends in independent living program development. Data from project surveys were used to assess the types of services being provided for persons with spinal cord injury, and the source and amount of funds being used. The survey instrument has been revised, expanded, and pilot tested. It will be readministered to all identified independent living programs. Data will be analyzed using univariate and multivariate techniques and will be com-

pared to earlier findings.

In order to facilitate use of the information that is developed, the project maintains a computerized bulletin board, a telephone communication network with all the extant independent living programs, and approximately 150 additional individuals. Knowledge transfer strategies depend on the specific topic or set of information, but they usually involve extensive reviews of existing literature, interviews with independent living program administrators, staff members, and consumers, and supplementary reviews by additional experts both in and out of the independent living field.

Preliminary Results—The findings of this work are being disseminated in several forms. A directory listing all identified independent living programs is revised on an ongoing basis. A registry profiling 164 independent programs in detail is available to spinal cord injury treatment programs, persons with spinal cord injuries, and others interested in independent living. An analysis of the data listed in the registry has been prepared as a monograph in the

ILRU Occasional Paper series. A new edition of the registry and analysis will be published after completion of the current survey. The ILRU project is continuing its training, networking,

and information dissemination activities in the area of independent living and maintains an ongoing effort to update its databases.

Assessment, Development, and Clinical Applications of Strategies to Coordinate Services for Spinal Cord Injured Clients After Discharge

D. Rintala, Ph.D.; J. Alexander, Ph.D.; E. Williams, Ph.D.

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *National Institute of Handicapped Research*

Purpose—There are three major project objectives: 1) assess current strategies employed after discharge to achieve psychosocial adjustment and productive lives for spinal cord injured persons; 2) develop and test new strategies or refine current strategies to enhance outcomes post-discharge; and 3) facilitate the integration of new and tested strategies into the service delivery system at The Institute for Rehabilitation and Research (TIRR) and disseminate the strategies to other appropriate sites. Methods include interviewing rehabilitation professionals and spinal cord injured clients to assess needs and resources, collaborating with service providers to develop and test improved strategies to address unmet needs, and assisting integration of the improved strategies into the service delivery system. Approximately 150 spinal cord injured persons more than 14 years of age who were admitted to TIRR for comprehensive rehabilitation from 1979 to the present will be interviewed. Rehabilitation professionals from a variety of disciplines will be interviewed and/or serve as an advisory committee.

The benefits expected from this project include meeting needs early to avoid compounding problems, utilizing resources efficiently by tailoring programs to meet the actual needs of clients, and improving rehabilitation outcomes by providing appropriate services.

Progress—A protocol was developed for interviewing rehabilitation professionals. Eight professionals from six rehabilitation disciplines were asked to describe the needs of SCI clients following discharge, the resources available to

meet those needs, and the systems for linking the clients with the appropriate resources. Eight broad categories emerged: health; activities of daily living; living arrangements; vocational; psychosocial; transportation; financial; and societal issues and policies. The list of needs described by the professionals was used to develop an interview protocol for use with clients to determine needs, utilization of formal and informal resources, links, resources, satisfaction with resources, and special difficulties encountered in meeting their needs.

Preliminary Results—From a pool of approximately 600 eligible clients, 136 interviews have been completed. Data collection will continue throughout 1986. Preliminary analyses of the first 97 interviews indicated major differences in selected variables when subjects were grouped by race, sex, marital status, extent of injury, and time since injury. For example, 31 percent of the whites were employed. Males had an average monthly income of \$1156; females averaged \$611. Married clients were more likely to live in a house, have family as visitors, and be concerned with the psychosocial aspects of sexual problems than were the unmarried clients.

We are working collaboratively with the National Spinal Cord Database and the RTC project on Outcome Studies Pertinent to the National Model Spinal Cord Injury System. Requested preliminary data have been shared with the medical director, outpatient clinic, and vocational department.

Longitudinal Assessment of Physical Therapy Factors in the Rehabilitation Process that Affect the Quality of Life of Spinal Cord Injured Persons

L. Don Lehmkuhl, Ph.D.

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *National Institute of Handicapped Research*

Purpose—The primary objectives of this study are to: 1) determine the importance of the patient's compliance in performing weight-shifts in a wheelchair to prevent breakdown of skin in weightbearing areas of the body; 2) improve the criteria and procedures for selecting which spinal cord injured patients should be braced and trained to become functional ambulators; and 3) determine the incidence, characteristics, and outcome of pain complaints in patients with severe spinal cord injury.

Progress—Reductions in the original level of funding necessitated reduction in the scope of the project being undertaken. Considering the resources and expertise available, we elected to defer action on objective 1 and concentrate on objectives 2 and 3. As we complete work on objectives 2 and 3, we will redirect staff effort to pursue objective 1. Patients being studied are individuals who received severe injuries to their spinal cord resulting in paraplegia or quadriplegia.

A total of 70 patients between the ages of 20 and 58 years with paraplegia have been studied in pursuing objective 2. A list of patient attributes and equipment services associated with the gait training program was compiled for each patient. Follow-up evaluations 6 months to several years after bracing are being made to assess brace utilization. We expect the results to improve the criteria for selection of those who will remain users of braces.

A total of 135 patients between the ages of 11 and 80 years (74 with quadriplegia and 61 with paraplegia) are being studied in pursuing objective 3. Information on pain status, method

of treatment, and reported success of treatment is gathered on a weekly basis until time of discharge. We expect the results to illustrate trends in etiology and resolution of pain complaints. An additional 25 patients are participating in a prospective study of the effectiveness of specific therapeutic interventions in relieving specific types of pain complaints.

Preliminary Results—Thus far we have: 1) analyzed the results of brace utilization by 70 patients who received bilateral knee-ankle-foot orthotic devices and drafted a report of the findings; 2) begun pilot studies with an orthotist to devise a simplified, modular lightweight orthotic device for early bracing and gait training; 3) gathered and categorized data concerning the pain complaints made by 135 patients with spinal cord injury during their initial hospitalization for comprehensive rehabilitation; 4) examined correlations between population variables, etiology of injury, level and neurological completeness of injury, and location and suspected etiology of pain complaint; 5) documented the status of each pain complaint at the time of discharge; 6) identified therapeutic procedures that patients reported as most effective in alleviating individual pain states; and 7) initiated a prospective study (N currently = 25) designed to test the relative effectiveness of specific therapeutic interventions in alleviating particular types of pain.

We plan to continue analyzing these data to look for relationships that will shed additional light on the mechanisms responsible for the state of discomfort and the mechanisms responsible for alleviation of discomfort.

Longitudinal Assessment of the Utilization of Upper Extremity Assistive Devices Prescribed for the Spinal Cord Injured Quadriplegic

Susan Garber, M.A., O.T.R. and Theresa Gregorio, O.T.R.

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *National Institute of Handicapped Research*

Purpose—Upper extremity assistive devices are frequently prescribed during the rehabilitation of SCI quadriplegics. However, though these devices are used daily during hospitalization, they may be discarded once the individual leaves the hospital environment. The primary objectives of this study are to: 1) identify functional categories of assistive devices prescribed for quadriplegics; 2) determine utilization and satisfaction with those devices 1 year and 2 years following rehabilitation; and 3) determine factors responsible for discarding devices.

This is a longitudinal prospective investigation in two parts. Phase I of this study is a review of 102 quadriplegics to determine functional categories and frequency of prescription of upper extremity assistive devices. Phase II employs an oral questionnaire of 75 patients to ascertain utilization of and satisfaction with devices prescribed during a first rehabilitation experience. This questionnaire is administered 1 and 2 years following discharge.

Satisfaction is determined using a Likert scale. It addresses the device characteristics of fit, cosmesis, and mechanical and functional performance. Factors that result in discarding a device include improved physical function, mechanical failure, alternative solutions, modification of living arrangements, noncompliance, and device outgrown or unattractive.

Progress—To establish the functional categories and frequency of prescription of upper extremity assistive devices, 102 charts of quadriplegic patients were reviewed. Feeding devices were prescribed to 49 percent, splints and slings to 87 percent, dressings to 30 percent, hygiene/grooming to 22 percent, and communication devices to 20 percent. An oral questionnaire developed to determine device utilization and level of satisfaction was administered to 77 former patients 1 year following their first re-

habilitation experience. For these patients 262 devices had been prescribed. Sixty-seven devices were for feeding. One hundred and sixteen patients received splints and slings; 18 received dressings; 19, hygiene/grooming; 17, communication; and 8, miscellaneous. At the end of 1 year, 151 devices (58 percent) were still in use (36, feeding; 75, splints and slings; 7, dressings; 8, hygiene/grooming devices; 17, communication devices; and 8, miscellaneous). On a scale of 1-5 (5 being the most satisfactory), those devices still in use were rated an average of 4.24. The most frequently cited reasons for discarding devices were improved physical function and alternative solutions found. Discarded devices represented a cost of \$5400 or 35 percent of the total expenditure for all devices.

Of the original population, 43 were queried 2 years post-rehabilitation. Of the devices prescribed during their first rehabilitation experience, 71 percent were still in use 2 years later with an overall level of satisfaction of 4.24 with retained devices. The remaining 22 subjects will be queried and the data recorded.

The overall costs of devices prescribed for subjects during their hospitalization were \$17,831. The costs of devices discarded during the first year following rehabilitation were \$5,860 or 32 percent of the total expenditure.

Preliminary Results—The results of this study have already influenced some of the prescription practices within the occupational therapy department. Therapists consider less expensive short-term devices rather than ordering the most expensive models of the same item. Furthermore, the OT staff is relying more on department-owned equipment from which patients may be weaned prior to discharge. Data on specific devices are being scrutinized to establish practical guidelines for their continued prescription.

Outcome Studies Pertinent to the National Model Spinal Cord Injury System_____

M. Fuhrer, Ph.D.; R. E. Carter, M.D.; W. H. Donovan

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *National Institute of Handicapped Research*

Purpose—This project encompasses three studies, two retrospective and one prospective, aimed at providing additional evidence about the effectiveness of the National Model Spinal Cord Injury System Project administered previously by RSA and currently by National Institute of Handicapped Research (NIHR).

The two retrospective studies capitalize upon existence of the common database established by the national systems. One study is an attempt to demonstrate that the highly advanced system of care practiced at the Royal Perth Hospital in Australia results in better patient outcomes than obtained in the less advanced care systems in the United States. The second study is concerned with documenting post-rehabilitation outcomes for quadriplegic patients who, at discharge from inpatient rehabilitation, require ventilatory assistance.

The prospective study will compare the outcomes of two groups of patients. One consists of patients whose acute and rehabilitation care was provided by the Texas South Central Regional Spinal Cord Injury (T/SCRSCI) System. It is comprised of four acute care hospitals in the Houston-Galveston area and The Institute for Rehabilitation and Research (TIRR) as the rehabilitation setting. The second group will consist of patients who were discharged from the same four acute care hospitals but who did not receive rehabilitation services at TIRR.

Data for TIRR patients are being obtained in a companion project entitled, "Assessment, Development, and Clinical Application of Strategies to Coordinate Services for Spinal Cord Injured Clients After Discharge." Data for non-TIRR patients will be obtained during home interviews using an adapted form of the interview used in the companion project.

Progress—During the project's first year, the U.S.-Australian systems study directed by Dr.

William Donovan was completed, and an article was published in *Paraplegia* in 1984. In that study, one data set reflected experience with 65 consecutively admitted patients who were cared for during 1979 and 1980 in the spinal cord unit at the Royal Perth Rehabilitation Hospital in Perth, Western Australia. A second data set pertained to 1606 US patients who had been cared for in one of the regional systems during the same year.

Preliminary Results—The results indicate that decubitus ulcers, atelectasis, pneumonia, pulmonary emboli, ulcers of the gastrointestinal tract, and heterotopic ossification all occurred more frequently in the US group. The difference was particularly marked for decubitus ulcers and urinary tract infections. These outcomes demonstrate that the sooner spinal cord injured patients are referred to a center capable of meeting all their needs, the less likely it is that they will develop complications that slow rehabilitation progress.

Analyses for the study concerned with post-rehabilitation outcomes for ventilatory dependent quadriplegics have been completed, and an article has been accepted for publication in *Archives of Physical Medicine and Rehabilitation*. Compared with ventilator independent quadriplegics, ventilator dependent individuals had a longer duration of hospitalization, less self-care capability, more hours per week of hired attendant care, and more hours of actual physical assistance per day. The groups did not differ significantly in terms of duration of inpatient rehabilitation, duration of rehospitalization, and vocational or prevocational status at the time of followup.

The prospective study comparing outcomes for system and nonsystem patients is continuing. Complete data are available currently for 136 system patients and 25 nonsystem ones.

Development of Reconditioning Exercise Program for Patients with Paraplegia_____

David Cardus, M.D.; W. G. Taggart, B.S.; F. Ribas-Cardus, M.S.

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 97030

Sponsor: *National Institute of Handicapped Research*

Purpose—The overall purpose of this project is to develop a testing methodology and to evaluate an exercise training program for the physical reconditioning of the patient with paraplegia. The expected outcome is the formulation of guidelines for the prescription of exercise and the documentation of the effects of physical conditioning programs for the patient with paraplegia. Male paraplegics between 18 and 50 years of age, free from disorders which contraindicate relatively high levels of exercise, and who have reached a suitable status in their rehabilitation process, will be selected for participation in the project. A minimum of five patients is to be studied in each of five categories of training modalities.

Each participant will be initially administered an exercise stress test consisting of interviews, blood sample for biochemical analyses, resting ECG, physical exam, and a graded arm ergometry test using an interrupted steady-state protocol. Expired gas will be collected during the last minute of each exercise phase. The training program modalities will consist of prescribed unsupervised exercise at home or exercise in a gamefield especially designed for wheelchair patients. Other patients will perform prescribed exercise under supervision in the laboratory or gamefield. Initially, the exercise period is for 5 to 10 minutes increasing to 20 to 25 minutes with training. Training will be

3 to 5 days per week for 3 to 12 weeks. After training, the patient will be subjected to a post-training study in which the testing of the first study will be repeated.

Progress—Two arm exercise training ergometers have been purchased and are currently being used in prescribed home training programs. One patient has procured his own trainer and is following a prescribed exercise program at home.

The assessment of the cardiovascular tolerance to physical work with arm exercise has been extended to 30 untrained paraplegic males, some more than one time for a total of 41 tests. In addition, 13 healthy males have been tested in the same manner, a total of 22 tests, for obtaining comparative data. Nine of the paraplegic males and seven of the healthy males have been tested in the gamefield for evaluation of energy requirements of specific athletic events. To date, five paraplegic males have been placed on a prescribed training program at home. Two patients on home programs were previously trained in the laboratory with extension of the program at home. Healthy subjects have been tested in the laboratory using leg and arm exercise protocols for comparing the mechanical efficiency of different muscle groups.

Vocational Evaluation for Quadriplegics with a High School Education or Less _____

W. Alfred, B.S.

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *National Institute of Handicapped Research*

Purpose—The project objective is to develop a vocational evaluation process that will expand the vocational options for spinal cord injured persons who are quadriplegic, who have a high school education or less, and who have either a limited work record or a job history incompati-

ble with current functional limitations. Methodology involves: 1) identifying and documenting jobs that can be performed by the described population group; 2) conducting a comprehensive review of existing vocational assessment tools and determining relevance of the tools to

assess the potential of quadriplegics; 3) selecting and organizing a meaningful process; 4) incorporating the model vocational process into the Vocational Department's service delivery program; and 5) evaluating the effectiveness of the model evaluation process.

The expected outcome of this project is the establishment of a more effective and realistic vocational evaluation process that can be used to assess the job potential of quadriplegics. The project also may have implications for other groups with severe physical impairments.

Progress—The developmental phase of the project has been completed. Of 12,278 jobs listed in the *Directory of Occupational Titles*, 497 were judged to be options for quadriplegics with a high school education or less. Labor market surveys were conducted to identify the occupa-

tional outlook among these jobs. Findings indicated that jobs in clerical and sales occupations were the largest in demand. The outlook for jobs in machine trades and benchwork occupations was discouraging.

A total of 334 vocational assessment tools were reviewed, and 105 of these tools were determined by the project staff to be within the physical capabilities of persons with quadriplegia.

The project staff has matched those assessment tools that appear to measure the duties of those jobs that have the best occupational outlook for the future. This has resulted in a vocational evaluation process that includes psychometric testing, work sample testing, simple work modifications, training in compensatory techniques, and limited situational assessment.

A Center for Acute Spinal Cord Injury: Epidemiology and Economic Costs of Spinal Cord Trauma

John D. Thompson

Yale University Medical School, New Haven, CT 06510

Sponsor: *National Institutes of Health*

Purpose—This program is a multidisciplinary approach to the problems of spinal cord injury (SCI). Included are an epidemiological study of spinal cord injury in Connecticut with delineation of incidence, cause, evaluation of treatment, and cost comparison of treatment in an organized SCI center and community hospitals in Connecticut. We will determine when stability of neurological function occurs; study animal models of spinal cord injury, evaluating various treatment modalities; observe the effects of trauma on spinal cord blood flow and metabolism; determine spinal column stability through

studies that include computer models of primate spinal column; determine post-traumatic alteration in blood-spinal cord barrier and the effect of biogenic amines on the resulting neurological dysfunction and ultrastructural analysis of impact trauma; develop a model system in larval lamprey (*Petromyzon Marinus*) for study of regeneration in the central nervous system; study the formation of regeneration in the central nervous system, the formation of peripheral neuroma and the factors controlling its size, and the olfactory bulb reestablishment of central synaptic connection following injury.

B. Medical Treatment

A Collision Block Technique for Micturition Assist: Preclinical Studies

J. Thomas Mortimer, Ph.D.

Case Western Reserve University, Cleveland, OH 44106

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation and the National Spinal Cord Injury Association*

Purpose—This animal study is in two parts: 1) to test the long-term effectiveness of implanted collision block electrodes in producing relaxation of the external urethral sphincter; and 2) to evaluate the long-term effects of the collision block stimulation and electrodes on peripheral nerve tissue to estimate the risk a patient must assume if a collision block electrode device were implanted.

The study is an important next step in an effort that addresses urinary complications of bladder paralysis, a major health problem facing a majority of patients with spinal cord injury.

Progress—The initial design and construction phase of collision block electrodes has been completed. Testing the short-term efficacy of the device in producing the type of pudendal nerve excitation necessary at the urethral sphincter is now underway. Some progress has been made in demonstrating that the initial design is sufficient to cause a response by the sphincter indicative of that needed to produce a collision block.

Future Plans—Short-term testing will continue, aimed at a best design for long-term implantation in animals.

A Laboratory Test to Predict and Monitor Bone and Skin-Related Complications in Spinal Cord Injured Patients

Jacqueline Claus-Walker, Ph.D.

Baylor College of Medicine, Houston, TX 77030

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation*

Progress—This research project is in its second year. Patient intake has been completed. The investigators monitor the list of clinic appointments. All patients who make an appointment are sent a letter asking them to bring a 24-hour urine sample when they come. This is followed by a phone call two days before the appointment. In addition to the above procedures, a general mailing is sent to all the patients in the project accompanied by a plastic sample bottle. Twenty-four hour urine samples are collected from any patient readmitted to the Institute for any reason. We hope that as a result of these efforts, each of the investigators will have several urine samples on each patient recruited into the project.

Preliminary Results—Medical charts are reviewed to assess the temporal relationship between the appearance of clinical symptoms of bone and skin related complications and the urinary concentration of the galactosyl hydroxylysine and glucosyl-galactosyl hydroxylysine, respectively. Results are following the same general trend that was found in the first year of the study. The excretion of both glycosides increases after the trauma, reaching a peak at approximately 3 months after injury and then gradually declines, reaching control values sometime between 6 months and a year after injury, if there are no complications. If there are skin or bone related complications, the excretion of the glycosides remains high.

Future Plans—Work is proceeding according to schedule. When the project is completed, the investigators expect to have enough data for a

valid statistical analysis which should contribute valuable information on collagen metabolism in spinal cord injury.

Skin Temperature in Spinal Cord Injury Related to Skin Breakdown

Michael Weiss, M.D., M.P.H.

Stanford University Medical Center, Stanford, CA 94305

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation*

Purpose—This study applies an existing technology—liquid crystal thermography—to detect early signs of skin breakdown and thus reduce the incidence of decubitus ulcers that are a major cause of morbidity and even mortality in spinal cord injured patients.

First, skin temperature pressure response norms in nonspinal cord injured and at-risk SCI subjects will be established. Then a controlled study of the at-risk group will compare thermogram-monitored and nonmonitored groups,

using commonly practiced protocols. It is believed that the thermally monitored group will build skin tolerance faster and with less risk of skin complications than the control group.

A substudy on cushion selection will determine which of several types of cushion will allow fastest return to baseline skin temperature. Forty nonspinal cord injured and 40 at-risk spinal cord subjects will be tested. A comparison of thermogram and standard cushion selection techniques will be made.

Prospective Randomized Clinical Trial of Thyrotropin-Releasing Hormone as a Therapy for Spinal Cord Injury

Laurence Pitts, M.D.

University of California, San Francisco, CA 94143

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation and The American Paraplegia Society*

Progress—It has been found that thyrotropin-releasing hormone (TRH) acts as a partial physiological antagonist of the endogenous opioids without altering pain thresholds. After traumatic spinal cord injury in cats, TRH has proven superior to other compounds in improving motor recovery. Earlier studies of TRH in human spinal cord injury indicated that the compound is safe at doses beneficial in experimental spinal injury. Its safety has further been demonstrated in studies of patients with amyotrophic lateral sclerosis, but no controlled clinical studies have been done to evaluate the use of TRH in human spinal cord injury.

Future Plans—Patients admitted to San Francisco General Hospital who have received a

nonpenetrating spinal cord injury will begin participating in the study within 24 hours of injury. After baseline evaluation that will include somatosensory-evoked potential recordings and quantitative neurologic examination, patients will be assigned randomly to either a TRH-treatment group or to a placebo control group. Treatment will consist of 6-hour intravenous infusions of TRH (0.2 mg/kg bolus followed by 0.2 mg/kg/hour) versus physiologic saline. Medical and/or surgical therapy as directed by the attending physician will not be affected. Follow-up studies will be performed at 24 hours, 1 week, 3 months, and 6 months after initial treatment. At least 30 patients per year are expected to participate.

Respiratory Dysfunction in Spinal Cord Injury: Control of Ventilation

Robert Brown, M.D.

VA Medical Center, West Roxbury, MA 02401

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation*

Progress—Individuals with spinal cord injury (SCI) frequently suffer complications resulting from respiratory system dysfunction. Although weakness of the breathing muscles is the most obvious contributing factor, it is not the only one. The act of breathing is a complex process involving the brain or controller, which determines when and how much one breathes; the chest wall and muscles of ventilation, which move air in and out of the lungs; and 'loads' or obstacles to the movement of air, such as narrowing of the bronchial tubes seen in individuals with asthma. The respiratory problems in spinal cord injury are now believed to result from derangement in one or more of these components of the respiratory system.

Future Plans—In this research some of the physiologic interactions among the controller, generator, and load will be analyzed. The extent to which the very low responsiveness to carbon dioxide by chronic paraplegic and quadriplegic patients is the consequence of mechanical factors, muscle weakness, changes in functional residual capacity during the maneuver, and paradoxical movement of the chest wall as opposed to an alteration in the 'gain' of the system, i.e., the controller, will be assessed. The latter will be investigated in part through manipulations of neurohumoral compounds (endorphins) which may be elevated in SCI. Finally, the effect of ventilatory muscle training on ventilatory responsiveness in SCI will be examined.

Urinary Bladder Ganglion Reorganization Following Lesions

A. Marshall Booth

University of Pittsburgh, Pittsburgh, PA 15260

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation and the National Spinal Cord Injury Association*

Progress—Urinary bladder dysfunction is one of the more important and common problems occurring in spinal cord injured patients. The degree and type of bladder dysfunction depends on the level and severity of the spinal injury, as well as on the length of time following the injury. For example, complete lesions above the sacral segment elicit an initial block of bladder reflexes with urinary retention followed by slow recovery of involuntary reflex bladder retractions. Bladder emptying is usually incomplete due to the loss of coordination between bladder and sphincter functions.

Future Plans—These studies will examine the pathological changes in bladder and pelvic ganglia of the cat and rat resulting from sacral lower motor neuron (SLMN) lesions. Symptoms

manifested in these species after SLMN lesions resemble those observed in humans who have sustained similar lesions. Frequently the immediate clinical consequence of SLMN lesions is bladder areflexia and urinary retention. Over a period of weeks or months, some bladder activity may appear, which results in partial bladder emptying if urethral sphincter innervation is not damaged, or incontinence if the sphincter pathways have been interrupted. Gradually, bladder tone tends to increase abnormally. The mechanisms responsible for the hypertonic autonomous bladder are far from clear and the treatment of the symptoms remains problematic. These studies combine intracellular recording, dye injection, and immunohistochemistry to examine the resulting pathophysiology.

Pharmacokinetics of Drugs in Spinal Cord Injured Persons

Stuart Feldman, Ph.D.

University of Houston, Houston, TX 77030

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation*

Purpose—The aim of this investigation is to determine whether the pharmacokinetics of certain drugs are different in SCI patients compared to nonspinal cord injured individuals. Previous studies have indicated that after an intravenous injection of tobramycin, the concentration of the drug in the bloodstream of the spinal cord injured person may be lower than that found in other individuals. Examination of the pharmacokinetics of aminoglycoside antibiotics (gentamicin, tobramycin, amikacin, and netilmicin) will be undertaken and the antispasticity drug, dantrolene sodium, will be investigated in hospitalized SCI patients.

Future Plans—During the first year, the pharmacokinetics of each antibiotic after intravenous and intramuscular administration is being examined. Dantrolene sodium is often prescribed for SCI patients to treat spasticity, but it is known to be slowly and incompletely absorbed by able-bodied persons, which suggests that the high doses often prescribed for SCI patients may be inappropriate. The absorption and metabolism of this compound administered intravenously and intramuscularly will be examined and the results compared with those obtained with able-bodied volunteers when an oral route of administration was used.

Actions and Metabolism of TRH in the Spinal Cord

Chandan Prasad, Ph.D.

Louisiana State University Medical Center, New Orleans, LA 70146

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation*

Purpose—This research is aimed at understanding and finding solutions to the problems associated with long-term use of thyrotropin-releasing hormone (TRH) for the treatment of spinal cord injury. Three interrelated areas will be explored, with a view to greatly improving the treatment of acute spinal cord injury with TRH.

In the first phase, the downregulation of TRH and upregulation of pharmacologic agents, such as desamethasone, estrogen, Hydergine, and Propylthiouracil (PTH) of rat spinal cord TRH-receptor will be examined during *in vivo* administration of these drugs. The ability of the above compounds in attenuating the downregulation of receptor TRH metabolism will be explored. A number of TRH-analogues will be screened for their ability to inhibit TRH metabolism in spinal cord extracts. The third goal will be to study TRH-mediated recovery of acute SCI using a superactive and superstable TRH-analog under conditions where both recep-

tor downregulation and TRH metabolism are pharmacologically attenuated.

Progress—The rationale for this approach is that treatment of animals with inhibitors of TRH-metabolism will not only increase the level of endogenous TRH but also augment the half-life of exogenous TRH and thus facilitate recovery from spinal cord injury.

The investigators have screened a variety of TRH-analogs that do not bind to TRH receptors for their ability to inhibit TRH metabolism and thus raise the level of endogenous TRH. Preliminary screening has uncovered four such analogs, and these results will be published shortly. In solving the problem of TRH-receptor downregulation, the potential effects of glucocorticoids, Hydergine, and PTH on receptor downregulation will be evaluated. These three agents were selected because they are known to upregulate TRH receptors in the brain and pituitary gland.

Factors Affecting Sodium and Water Homeostasis in SCI

Domenic A. Sica, M.D.

Virginia Commonwealth University, Richmond, VA 23284

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation*

Purpose—The major thrust of this research will be to examine in each patient the multiple factors capable of influencing the release of antidiuretic hormone. Patients participating in these studies have sustained *a priori* (minimum of 6 months) cervical cord transection and will be evaluated for their response to a number of superimposed stimulator and/or inhibitory variables capable of affecting changes in the release of antidiuretic hormone. Such provocative stimuli include the fusion of hypertonic saline, tilt-table induced hypotension, ethanol infusion, angiotensin II infusion, and the administration

of the dopamine antagonist, metoclopramide.

Future Plans—Serial blood sampling will occur in the course of performance of each test. Once the patterns of antidiuretic hormone release have been distinguished, it will become possible to extrapolate this information to those clinical situations most likely to be associated with hyponatremia. Furthermore, this appraisal of antidiuretic hormone will eventually afford considerable insight into the enigmatic relationship of this hormone with blood pressure.

Circulorespiratory Effects of Dynamic Arm Exercise in Spinal Cord Injured, Quadriplegic Males

Stephen F. Figoni, M.D.; Richard A. Boileau, Ph.D.; Benjamin H. Massey, Ph.D.; Joseph R. Larsen, Ph.D.; Alfred F. Morris, Ph.D.

University of Illinois, Department of Physical Education, Urbana, IL 61801

Sponsor: *American Corrective Therapy Association, Inc. and the Division of Rehabilitation-Education Services, University of Illinois, Champaign-Urbana*

Purpose—The purpose of this study was to determine the effects of sitting rest and dynamic arm exercise on selected circulorespiratory functions of spinal cord injured, quadriplegic men. These acute physiological responses were examined at rest, during two submaximal exercise stages, and during maximal exercise. Mean values and trends were compared with a group of able-bodied reference subjects.

Progress—The two groups of subjects included 11 untrained, male, C5-C7 complete quadriplegic university students and 11 able-bodied men of similar age, height, weight, and training status. Four exercise tests were administered to each subject using a Monark cycle ergometer modified for armcranking in the sitting position. Experimental methods included open-circuit spirometry, impedance cardiography, and electrocardiography.

Preliminary Results—The quadriplegic men nearly quadrupled their resting metabolic rates (oxygen uptake) through exercise to 30 percent of the maximal levels of able-bodied men. This was achieved primarily through tripling the rate of peripheral oxygen extraction toward physiological limits, while central oxygen delivery increased by very small amounts from rest to maximal exercise. The nearly constant cardiac output (4 l/min) resulted from an inverse relationship between the increasing heart rate and decreasing stroke volume. Low myocardial contractility, decreasing (although relatively high) ejection fraction, decreasing cardiac preload (end diastolic volume), and constantly low end systolic volume also characterized a 'hypokinetic circulatory syndrome' in upright exercising quadriplegics.

Future Plans—Research will delineate separate effects of orthostatic and exercise stress.

Neural Mechanisms Underlying Bladder Dysfunction After Spinal Trauma

Charles J. Robinson, D.Sc.; R.D. Wurster, Ph.D.; J.M. Bolam, M.S.
Veterans Administration Medical Center, Hines, IL 60141

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This project's goal is to learn more about the underlying mechanisms of bladder dysfunction following spinal trauma and to use this knowledge to develop ways to enhance the recovery of bladder function after spinal trauma. It complements our other studies, which focus on ways to overcome paralysis in humans.

We have two objectives for this project: 1) develop an animal model to study micturition dysfunction after spinal trauma and, 2) use this model to study the effects of various drugs on the spinal control of micturition. We chronically measure the relationship between bladder volume and pressure before and after the spinal administration of opiate agonists and antagonists, and before and after spinal trauma,

using pairs of ultrasonic crystals that have been implanted in the bladder wall and a miniature pressure transducer implanted into the bladder.

Our research should lead to a better understanding of the neurophysiology and neuropharmacology of bladder function, because we can measure and manipulate many of the neural and muscular events underlying bladder function in the unanesthetized animal. Such understanding is needed because renal complications remain the number one cause of death during the long-term management of the spinal cord injured patient. These complications are a direct result of the bladder dysfunction that almost always accompanies spinal cord injury.

Differences Between Chest Heat Patterns Shown by Complete and Incomplete Spinal Cord Injured Veterans

Richard A. Sherman, Ph.D.; Jeffrey L. Ernst, Ph.D.; Janusz Markowski, M.D.

DD Eisenhower Army Medical Center, Fort Gordon, GA 30905 and VA Medical Center, Augusta, GA 30910

Sponsor: VA Rehabilitation Research and Development Service and US Army Clinical Investigation

Final Results—Thermograms showing heat patterns in the trunk of the body were taken of 15 veterans diagnosed as having complete spinal cord injuries (SCI) and 7 veterans diagnosed as having incomplete SCIs.

All of the subjects with complete SCIs had a line across the trunk which represented a temperature gradation between a relatively warm upper level in which sensations were normal and a relatively cool lower level in which sensations changed.

One of the subjects diagnosed as being complete SCI showed almost no transition zone and

the temperature difference was less than that required for clinical interpretation. None of the subjects having incomplete SCIs produced this pattern. Only one incomplete SCI subject showed even a minimal difference in temperature between the normal sensation and abnormal sensation levels.

A panel blind to whether the subjects were intact, incomplete SCI, or complete SCI was unable to differentiate between intact and incomplete SCI subjects but was able to sort complete from incomplete subjects in all but one case.

The Spasticity of Spinal Cord Injury

James W. Little, M.D., Ph.D.

Veterans Administration Medical Center, Seattle, WA 98108

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Spasticity or the appearance of hyperactive spinal reflexes commonly develops gradually following spinal cord injury (SCI). This hyperreflexia often interferes with sleep, transfers, ambulation with braces, and other daily activities. Several neurophysiologic mechanisms, including loss of normal reflex inhibition, denervation supersensitivity, and collateral sprouting, have been proposed to explain the appearance of various clinical manifestations of spasticity.

This study will describe the temporal course of spinal reflex changes for 1 year following acute SCI, and will correlate electrophysiologic measures of hyperreflexia with clinical manifestations of spasticity. Reflex excitability in acute SCI subjects (less than 1 year post-injury) will be compared to observations in chronic SCI subjects and to control subjects without SCI.

Progress—To date, spinal reflex studies have been initiated in 6 acute and 5 chronic SCI subjects, and 14 control subjects. Preliminary observations suggest that tibial and femoral H-reflex excitabilities, measured as H/M ratios, are greater in chronic than in acute SCI sub-

jects. As expected, the clinically elicited tendon reflexes are most excitable in the chronic SCI subjects. Electrical stimulation of the sural nerve is followed by the recording of long latency cutaneomuscular (flexor withdrawn) reflexes in the biceps femoris (BF) and tibialis anterior (TA) muscles. In some, but not all, chronic SCI subjects these reflex responses to the TA muscle are of much larger amplitude than they are in any acute SCI or control subjects. Compound muscle action potentials (M-responses) are of much smaller amplitude in chronic SCI subjects than in acute SCI or control subjects, presumably reflecting disuse atrophy.

Additional serial observations are needed to confirm these preliminary observations. Another focus of the study will be to record *cauda equina* potentials to tibial nerve stimulation in acute and chronic SCI subjects. By calculating efferent/afferent ratios, as a measure of central excitability, and by comparing the size of the afferent volleys to tendon taps of measured force, as a measure of peripheral muscle spindle sensitivity, we will assess their relative contributions to the developing reflex hyper-excitability following acute SCI.

Effect of Intermittent Catheterization on Renal Stone Formation in Spinal Cord Injury Patients

J. R. Burns, M.D.

University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: National Institute of Handicapped Research

Purpose—Because spinal cord injury patients commonly experience alterations in calcium metabolism (hypercalciuria) which may persist for many months after injury, it is necessary to determine how, if at all, intermittent catheterization in the presence of hypercalciuria affects the risk of urinary tract stone formation. This study seeks to examine the effects of intermittent catheterization and determine the signifi-

cance of hypercalciuria in SCI patients.

Progress—The study population consists of patients with neurologically complete spinal cord injuries who are identified and entered into the study within 1 week of injury. Twenty-four-hour urine specimens are collected at admission and twice weekly thereafter until patient discharge. Serum calcium is measured. Urine pH

and species concentration measurements are obtained at regular intervals. Relative supersaturation of the urine with respect to calcium oxalate and calcium phosphate is determined. Activity product and the formation product ratio of brushite is determined for each urine specimen.

Preliminary Results—We are currently determining how intermittent catheterization in the presence of hypercalciuria affects the risk of

urinary stone formation in the acute spinal cord injury patient. As of June 1986, a total of 15 patients have been entered in the study. Although a preliminary analysis of the data has been done, as yet there are no significant findings to report.

Future Plans—We will continue entry and followup of patients in this study through May of 1987.

Natural History and Clinical Course of Urinary Tract Complications in Patients With Spinal Cord Dysfunction

S.L. Stover, M.D. and L.K. Lloyd, M.D.

University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute of Handicapped Research*

Purpose—Appropriate clinical management of patients with neurogenic bladders resulting from spinal cord dysfunction requires 1) knowledge of the natural history or clinical course of urinary tract complications in this group and 2) data from which to determine whether urinary complications in this group are predictable from early post-injury urinary tract status and method of early bladder drainage management.

The objectives of this study include: 1) determining the effect of method of bladder drainage management on the incidence of orchitis and/or epididymitis, penoscrotal abscess, penoscrotal fistula, ureterectasis, pyelocaliectasis, and effective renal plasma flow (ERPF); 2) determining the effect of various urinary tract infecting organisms on orchitis/epididymitis, penoscrotal abscess, penoscrotal fistula, ureterectasis, pyelocaliectasis, and ERPF; and 3) determining the effect of vesico-ureteral reflux on upper tract changes including ureterectasis, pyelocaliectasis, calculi, and ERPF.

Progress—Rigorous statistical analyses are being performed on a massive urologic database derived from a large series of SCI patients having a spectrum of neurologic levels and extents of injuries, and those neurogenic bladders are/were managed in a variety of ways.

Preliminary Results—Complete studies have been performed and data recorded on 327 patients from a retrospective study group and 571 patients from a prospective group, yielding a total of 898 completed studies to date. Of those patients who had used the same type of bladder drainage for at least 5 years, provisional analysis showed the mean ERPF greatest in patients who emptied their bladders by straining, followed by those who voided at will, then those who used indwelling catheters. Further data suggest that maintaining sterile urine in SCI patients results in far fewer cases of urologic complications and surgical procedures, but that patients with untreated bacteriuria do not fare appreciably worse than patients with bacteriuria treated with antibiotics. SCI patients with *Serratia*, *Pseudomonas*, and *Providencia* had more urologic complications while those with *Staphylococcus*, *Enterobacter*, and *Enterococcus* had fewer complications. Additional data suggest that vesico-ureteral reflux improves with time (67 percent), though some patients continue to deteriorate (11 percent) and some continue with the same severity of reflux (22 percent).

Future Plans—Data collection is continuing. Currently, we are focusing attention on methods of bladder management and their association with urologic complications. We are exam-

ining the causes of diverticula, which have been identified as risk factors in the development of pyelocaliectasis. Finally, we will examine the

relationship between vesico-ureteral reflux and renal complications and function in the chronic phase of spinal cord injury.

A Bladder Sensor for Urinary Incontinence

Beth A. Mineo, Ph.D., and A.R. Cavalier, Ph.D.

Bioengineering Program, Department of Research and Program Services, Association for Retarded Citizens National Headquarters, Arlington, TX 76006

Sponsor: *National Institute of Handicapped Research*

Purpose—The research team is developing and evaluating an unobtrusive portable device to continuously monitor bladder volume using ultrasound. Such a device will assist persons with mental retardation who have not learned independent toileting skills to learn the critical association between the internal state of bladder distention and the act of engaging in a toileting routine. It will also allow persons with inadequate sensation to monitor their internal state, independently.

The device is expected to offer independence in toileting to many elderly persons as well as to persons with spinal cord injury, cerebral palsy, advanced diabetes, and *spina bifida*.

Progress—Among the primary considerations in the design of the device were attempts to keep the end-user cost of the device as low as possible and to obtain the most informative scan of the bladder for as little energy expenditure as possible. Toward the first of these objectives we are incorporating many off-the-shelf components.

In terms of energy consumption, a technique has been devised that will allow the system to use much less power than has previously been required, and will do this without sacrifice of imaging capability. This new approach also permits the system to rely on only a single transducer. At the present time, the

system consists of a small logic analyzer and a single miniature transducer.

The final version of the logic analyzer is expected to be the approximate size of a credit-card calculator, and the transducer will be located on a belt to be worn by the user. Alternate configurations will be customized to accommodate user needs.

In the first half of the project, a database of incontinence-related research reports, product manufacturers, and research projects, was compiled and computerized; anatomical parameters of bladder position were established; a prototype of the system was configured; and the experimental design of the field evaluations was developed.

Future Plans—During the remainder of the project, tests will be conducted to determine the reliability of the portable system as compared to proven ultrasound scanners that are large and stationary. Field-tests of the efficacy of the device in use in client service settings will provide information regarding the applicability of the system to persons who have not achieved independence in toileting due to cognitive and/or physical limitations.

The system will be refined in response to the information gained from the evaluation process.

Clinical Evaluation of an External Device for Urinary Care in Incontinent Women _____

David E. Johnson, Ph.D.; Jodie L. O'Reilly, R.N., B.S.N.; Frank M. Calia, M.D.

Veterans Administration Medical Center, Infectious Diseases Research Laboratory, Baltimore, MD 21218

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Chronic urinary incontinence, a frequent complication of spinal cord injury, multiple sclerosis, neurological defects affecting frontal lobe cortex, and advancing age, may be the pivotal factor determining whether a patient requires long-term institutional care. An estimated 2.4 million American women are incontinent of urine and that number is likely to exceed 3 million by the year 2000.

External urine incontinence devices for women, which have been described in the literature, are not commercially available. The customary methods for management of urinary incontinence in women, chronic use of indwelling urethral catheters or diapers, invariably lead to bacteriuria or infected decubiti in nonambulatory patients. Current methods of urinary care for incontinent women are costly in supplies, personnel time, and infections resulting from long-term indwelling catheter use. An effective external urine incontinence device for women would have an important impact in reducing both private and public medical care costs and may reduce catheter-associated urinary tract infections and their sequelae.

Progress—We have entered into joint studies with device manufacturers for development and clinical evaluation of external urinary incontinence devices for women. These joint studies include fabrication of prototype devices by the manufacturers and our clinical evaluation of prototypes in healthy volunteers and urinary incontinent inpatients.

We have clinically evaluated the performance of three different design concepts of prototype external urinary incontinence devices. A total of 255 of those devices have been evaluated. Preliminary design feasibility studies have been conducted in seven healthy female volun-

teers. Clinical efficacy studies have been conducted in 19 urinary incontinent, bedridden women in long-term care facilities. Patients selected had a history of urinary management problems resulting in chronic bed-wetting.

Results—In clinical efficacy studies, 88 percent of device applications resulted in complete patient dryness. Only three percent of applications or removals were scored as difficult. Device use resulted in patient comfort in 93 percent of applications. Mean effective device wear time was 22.3 hours. Minimal erythema (slightly red mucosa) was observed at the vaginal introitus in 12 percent of applications in studies evaluating devices for 5 consecutive days. In studies evaluating devices for 21 consecutive days, minimal erythema was observed on the peri-urethral floor and at the vaginal introitus after 47 percent of applications. Minimal erythema did not progress to more severe erythema, was not associated with patient discomfort, and may have been related in part to peri-urethral cleansing prior to each device application. Low level edema (< 1 mm) was observed following two of 26 applications in one patient. Device usage did not induce bacteriuria or infection of the vagina or peri-urethral mucosa. Based on results from our clinical evaluation of prototypes, we have recommended to manufacturers modifications in device configuration which may improve device wear time and effectiveness and reduce adverse reactions.

Evaluation of device modifications in healthy volunteers and bedridden, urinary incontinent women, evaluation of other prototype design concepts, and evaluation of prototype devices in ambulatory, urinary incontinent women are in progress.

Incidence, Characteristics, and Clinical Significance of Anemia in Patients with Spinal Cord Dysfunction

C.T. Huang, M.D.

University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute of Handicapped Research*

Purpose—Anemia commonly develops within the first 6 months following spinal cord injury (SCI), even in the absence of detectable blood loss. Whether anemia is due to stress, inadequate nutrition, blood loss, depressed red blood cell (RBC) production, or increased RBC destruction has not been determined. Anemia may be an important factor in the development of secondary complications. It may also delay or prolong the rehabilitation program. Thus, finding the cause of anemia in this population is a requisite to its prevention.

This study seeks to: 1) determine those epidemiologic and/or demographic variables affecting the duration and/or severity of anemia; 2) determine the natural history of changes in the hematologic profile of SCI patients; 3) establish the natural history of RBC kinetics after SCI; and 4) determine whether alterations in nutritional profile are associated with the incidence, duration and/or severity of post-injury anemia.

Progress—A series of neurologically complete quadriplegics (who have not received blood transfusions following their SCI) constitute the study population. Demographic characteristics and the hematologic correlates of the population are being documented as are basic hematologic profiles. Ferrokinetic studies are being performed. Nutritional profiles and their hematologic correlates are established. Erythropoietin quantitative assays are being performed.

All data will be analyzed utilizing appropriate statistical techniques.

Preliminary Results—The project was initiated in June 1984. As of June 1986, a total of 21 patients had been entered into the study. Nineteen patients were males between the ages of 18 and 55 with neurologic levels of lesion between C3 and C7. The female patients were ages 22 and 81.

The patients were evaluated an average of 42 days post-injury. They had serum erythropoietin values ranging from 4-75 milli-immunochemical units erythropoietin/ml. The normal reference values are 7-36 units/ml. Eight of the 14 patients agreed to participate in the plasma volume red cell mass, total blood volume, and total hematocrit studies using I-125 and Cr-51. These patients had a slightly lower red cell mass than normal but had higher plasma volumes. Total body hematocrit was also generally low. It appears that despite normal peripheral red cell, hematocrit and hemoglobin counts, the serum erythropoietin level is low during the acute stage of spinal cord injury. Shrinkage in red cell mass is also possible during this time period.

Future Plans—Patients will continue to be entered in the protocol until May 1988. Preliminary data analysis will begin in the fall of 1987.

Effects of Nutritional Intervention During the Acute Phase of Spinal Cord Injury

C.T. Huang, M.D.

University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute of Handicapped Research*

Purpose—This study, an outgrowth of "The Relationship of Nutritional Status and the Occurrence of Secondary Complications in Spinal Cord Injury Patients," is examining the

association(s) between improving nutritional status via aggressive nutritional intervention and the prevention of secondary complications and preservation of optimal immune, motor,

and psychological function. We are: 1) conducting a randomized 4-week trial of aggressive nutritional intervention (ANI) in SCI patients; 2) determining the effect of ANI on body weight, skin-fold thickness, serum diet-dependent proteins and blood vitamin and zinc levels; 3) determining the effect of ANI on incidence of secondary complications; 4) determining the effect of ANI on muscle circumference, strength and urine creatinine excretion; 5) determining the effect of ANI on T and B lymphocyte numbers, delayed cutaneous hypersensitivity, neutrophil bactericidal activity and production of salivary IgA; and 6) determining the effect of ANI on psychological parameters.

Progress—Forty-eight SCI patients with neurologically complete, sensory sparing only, or nonfunctional motor lesions, who are between

18 and 60 years of age and less than 60 days post-injury, are being entered into the study population. Half ($N=24$) will have cervical injuries and the remaining patients will have thoracic injuries. Patients with concomitant brain injuries or multiple fractures are excluded. Patients are being randomly assigned to 'treatment' and 'control/no treatment' groups.

Patients in the treatment group are given aggressive nutritional support for 4 consecutive weeks. During and after this time comprehensive nutritional, medical complication, muscle mass and function, immune function and psychological data are collected and analyzed. Appropriate data will be compared for possible identification of association(s) between physiological and psychological findings/responses and aggressive nutritional intervention.

Incidence and Clinical Significance of Impaired Brain Function in Spinal Cord Injury—

J.S. Richards, Ph.D.

University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: National Institute of Handicapped Research

Purpose—Incidence statistics on concomitant brain impairment in spinal cord injury (SCI) patients are lacking. Such data are needed both in the individual case and in the aggregate so that adequate planning and service offerings can be provided to patients who suffer this significant, associated injury. The goals of this study are to: 1) identify, validate, and utilize a battery of neuropsychological tests to diagnose impaired brain function in a series of recently injured SCI patients; 2) estimate the incidence of impaired brain function in recently injured SCI patients; 3) determine whether neuropsychological assessment data correlate, in a meaningful way, with demographic, epidemiologic, and medical data from the same series of SCI patients.

Progress—A neuropsychological test battery was identified, evaluated for appropriateness/applicability and validity, and subsequently administered to 150 newly admitted SCI patients. Medical, epidemiologic, and demographic data

on all patients in the series were reviewed retrospectively. All data, including neuropsychological test results, were or are in the process of being evaluated quantitatively and qualitatively. As this summary was being written, data sheets were being presented to a panel of neuropsychologists who do not know the neurologic condition of the patients. Based upon their review of patient-specific data, they will attempt to diagnose probable brain pathology. The incidence of concomitant brain and spinal cord injury will be estimated from their review and a determination made regarding the ability of neurological and descriptive measures to predict concomitant brain impairment in the SCI population.

Preliminary Results—As of November 1985, some 150 complete initial neuropsychological test batteries had been administered and scored, and all accompanying medical and demographic data recorded. Sixty-seven retest administrations were completed as well. Provi-

sional data inspection suggests more impairment across a wider variety of cognitive tasks

for a larger percentage of patients than reported previously.

Pain Secondary to Gunshot Wound During the Initial Rehabilitation Process in Spinal Cord Injury Patients

J.S. Richards, Ph.D.

University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: National Institute of Handicapped Research

Purpose—Surgical management of gunshot-related spinal cord injury (SCI) is controversial. There is concern that routine decompression laminectomies (in which the bullet and/or bullet fragments are removed) may aggravate the patient's prognosis rather than improve it. Removal of the bullet tends to be a standard practice whether or not its presence represents a life-threatening situation. It is widely accepted that removal reduces the intensity of associated pain later in life. However, there is virtually nothing in the rehabilitation literature supporting this contention.

By contrast, other clinicians believe laminectomy may contribute to general instability of the vertebral column in addition to being partially responsible for some reported pain. Finally, there is a clinical impression that pain occurring secondary to gunshot wound (GSW) may differ in character from that occurring secondary to SCI resulting from other causes.

This study will help clinicians understand intractable pain following SCI. It will also verify or refute the efficacy and desirability of decompression laminectomy and bullet removal after SCI. Specifically, this study seeks: 1) to determine whether the incidence of pain reported in GSW/SCI patients is significantly different from the incidence in patients whose SCIs result from other etiologies; 2) to characterize the incidence of pain reported by GSW/SCI patients epidemiologically and demographically; 3) to determine the relationship between the incidence of pain in GSW/SCI patients and surgical removal of the bullet; and 4) to determine, prospectively, the incidence of pain in gunshot wound SCI patients with or without decompression laminectomy.

Progress—This is a two-phase, prospective study. In Phase 1, pain data are collected on all SCI admissions (except those excluded because of overlying psychosis or senility) on a weekly basis from time of admission to first definitive discharge, with pain behavior changes being assessed over time. Data are evaluated with regard to epidemiologic and demographic characteristics of the population. GSW/SCI patient data are studied to determine absence or presence/location of the bullet or bullet fragment(s). If surgically removed before this phase, the pre-surgical location is documented. Pain history is documented and analyzed statistically. Eventually, all findings will be reviewed with our Department of Neurosurgery and a Phase 2, controlled study with random assignments of patients to surgical/nonsurgical management groups will be undertaken. Patient outcome will be evaluated.

Preliminary Results—At present, we evaluate all admissions to determine if specific patients can be relied upon to provide accurate data. We collect weekly pain data (pain behavior, subjective (0-10) ratings, and the McGill Pain Inventory) on GSW/SCI patients during their initial hospitalization, and at 6 and 12 months post-injury. As of April 1986, 44 GSW/SCI patients had been entered into the five GSW study groups with the following: bullet in canal ($N=10$); bullet present elsewhere ($N=8$); bullet removed from canal ($N=15$); bullet removed from other locations ($N=9$); bullet exited body ($N=2$). We also are collecting identical data on a control group of 50 non-GSW/SCI patients matched by neurologic level and extent of lesion, and in most cases by sex.

Didronel in the Prevention of Heterotopic Ossification Following Spinal Cord Injury: Determination of an Optimal Treatment Schedule

S.L. Stover, M.D.

University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute of Handicapped Research*

Purpose—Heterotopic ossification (H.O.) following spinal cord injury or other severe neurologic injuries and diseases can limit joint range of motion and exacerbate the disability, often impairing function and limiting ambulation or wheelchair independence to the extent the patient must remain bedfast. Recently, however, a new drug, Didronel (etidronate disodium), has been shown effective in preventing H.O. when administered prophylactically after spinal cord injury.

This study seeks to: 1) determine the optimal time post-injury that Didronel therapy should be initiated to achieve the maximal prophylactic effect; 2) determine the optimal duration of Didronel therapy for maximal prophylactic effect; and 3) establish dosage recommendations for Didronel that are capable of yielding maximal prophylactic effect.

Progress—The study population consists of patients admitted to the UAB-Spinal Cord Injury Care System between zero and 120 days post-injury, whose lesions are neurologically complete (or neurologically incomplete with residual function equal to a Frankel Classification of 'sensory only') who are at least 16 years of age and who are not pregnant. Patients in the series are subcategorized into early and late treatment groups and further divided into 3- and 6-month administration groups. X-ray films of both hips are obtained 1 day prior to initiation of Didronel therapy, at the end of each treatment period, and at 1 year post-injury.

Preliminary Results—As of June 30, 1986, some 190 patients had been entered into the study. Substantially more patients ($N=112$)

were entered into the early treatment groups (15-44 days post-injury) than there were patients ($N=78$) entered into the late treatment groups (45-120 days post-injury).

The study's major problem has been the high dropout rate. Of 190 patients entered into the study, 84 have been dropped from the protocol, primarily for reasons beyond our control. Eleven other patients acquired clinically significant H.O. and required continued drug treatment for at least 1 year.

Our preliminary results are based upon 95 patients with complete data. For patients who do not develop H.O., drug treatment for 180 days appears to be no more advantageous than treatment for 90 days regardless of when treatment begins. Clearly, early treatment is superior to late treatment regardless of duration.

Presently, the active study population consists of 109 patients who remain on the protocol and appear capable of and willing to be followed post-discharge. Ten patients have completed the drug treatment phase but have an annual followup examination pending. Four patients are currently completing the drug treatment phase.

Future Plans—This project was originally scheduled to be completed in May 1985. However, because of a somewhat greater than projected dropout rate, we have not achieved our target of 100 patients with complete data. Though we are following 109 patients currently, we expect to lose some of these due to dropout. Therefore, we have extended this project through May 1988 or until our 100 patient target is achieved.

The Relationship of Nutritional Status and the Occurrence of Secondary Complications in Spinal Cord Injury Patients

C. T. Huang, M.D.

University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute of Handicapped Research*

Purpose—Nutritional needs of spinal cord injury (SCI) patients are almost entirely a matter of speculation. There are many unanswered questions concerning protein requirements, lipid mobilization, and vitamin and mineral requirements. This study attempted to: 1) determine the frequency of nutritional deficits in recently injured SCI patients; 2) document secondary medical complications and examine the association between them and low or deficient nutritional parameters; 3) examine the association between muscle mass, strength and endurance, and low or deficient nutritional parameters; 4) assess T and B lymphocyte numbers, cutaneous hypersensitivity, neutrophil bactericidal activity and production of salivary IgA as indicators of immunologic function, examining the association between decreased immunologic function and low or deficient nutritional parameters; and 5) assess depression, self-concept, and anxiety as indicators of psychological functioning, examining the relationship between psychological parameters and low or deficient nutritional parameters.

Progress—A series of 60 SCI patients with neurologically complete lesions, sensory sparing only, or nonfunctional motor capabilities who were between 15 and 60 years of age, without multiple fractures and without concomitant head injury, were studied throughout the course of hospitalization in the rehabilitation setting. A wide spectrum of nutritional varia-

bles was measured at regular intervals. Nutritional deficiencies and secondary medical complications developing after admission were documented and analyzed statistically. Muscle mass and work capacity were determined and analyzed. Immune fractions were determined at regular intervals after admission. Also, psychological evaluations were performed at regular intervals after admission.

Preliminary Results—Data were collected on 51 patients. Twenty-one had cervical injuries, 16 had thoracic injuries at or above T10, and 14 had injuries below the tenth thoracic segment. Preliminary findings indicated that caloric intake was frequently less than 1000 calories per day for prolonged periods. Other values found frequently to be low include carotene, folate, ascorbate, transferrin, and copper. Anergy to mumps antigen, as reflected in delayed cutaneous hypersensitivity (DCH), was present in 87 percent of the patients, compared to 30 percent of healthy controls. Patients with low maximal inspiratory pressure (MIP) tended to have more nutrient deficiencies than those with normal MIP, and those with low maximal expiratory pressure (MEP) tended to have more nutrient deficiencies than patients with normal MEP.

Our findings suggest nutrient deficiencies are common in the acute phase of SCI and appear to be associated with depressed immune response and muscle function.

Collagen Dysfunction in Quadriplegia

Gladys Rodriguez, M.S. and Jacqueline Claus-Walker, Ph.D.

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *National Institute of Handicapped Research and the Technology and Research Foundation of the Paralyzed Veterans of America*

Purpose—This study seeks to elucidate the ways in which collagen metabolism is altered in

spinal cord injury and determine the causes and consequences of such alteration.

Project I: A method has been developed to measure hydroxylysine glycosides in an automated amino acid analyzer to establish the fact that increased concentration of a specific glycoside is an indication of the tissue origin of the collagen being degraded. It is hoped that physicians will be able to use this information to decide what preventive measures are of greatest importance for the individual patient and thus reduce the number of complications following SCI.

Project II: Density of adrenergic receptors in the insensitive skin of SCI patients is being measured by radioligand binding assays. The objective is to show that altered sympathetic responses lead to altered nutritional status of skin, thus increasing its susceptibility to pressure damage.

Project III: The activity of the enzyme lysyl hydroxylase and the concentration of some amino acids characteristic of collagen are being measured in skin biopsies from above and below the injury in SCI patients. The objective of this project is to show that SCI leads to ab-

normal enzyme activity which in turn leads to defective collagen biosynthesis and decreased tensile strength of the skin. If the specific defects in the collagen metabolism of SCI can be identified, they may be amenable to pharmacological intervention.

Progress—Project I: Eighty-six patients have been followed for up to 3 years after injury. Data are being summarized and analyzed at this time.

Project II: Data have been published in the *Archives of Physical Medicine and Rehabilitation* (67:177-180, 1986). Control biopsies have been obtained and efforts to increase the patient database continue.

Project III: Biopsies have been obtained from healthy, nonparalyzed volunteers. The number of patients is small, but data so far indicate that lysyl hydroxylase activity is highest in healthy controls, next highest in the skin above the level of injury in SCI patients, and lowest in skin below the level of injury of SCI patients.

Effects of Spinal Cord Injury on Drug Metabolism

Lauro Halstead, M.D. and Stuart Feldman, M.D.

Baylor College of Medicine, The Institute for Rehabilitation and Research, and Department of Pharmaceutics, University of Houston, Houston, TX 77030

Sponsor: *National Institute of Handicapped Research and Paralyzed Veterans of America*

Purpose—The pharmacokinetics of medications administered to spinal cord injured (SCI) patients have not been widely investigated. There are numerous reports regarding alterations of normal physiological, neurological, and biochemical functions in the SCI population, which raise the possibility that one or more aspects of drug distribution, metabolism, and excretion may be altered in this group. The overall objective of this research is to investigate, in a systematic fashion, a number of representative drugs commonly used at various times throughout the life of SCI patients.

Progress—Eighteen subjects with SCI who were to receive tobramycin either prophylactically prior to a urological procedure or to treat infec-

tion were given an explanation of the research project and gave written informed consent. All subjects had normal renal function as evidenced by creatinine clearance measurements. Eighty milligrams of tobramycin were infused intravenously by a pump over a 60-minute period. Serum samples were collected before the infusion and at 30, 60, 75, 90, 120, 150, 180, 240, 360, and 480 minutes after the start of the infusion. Serum samples were assayed for tobramycin by the EMIT method of analysis. Data were analyzed by model-independent pharmacokinetic methods.

The mean age of our subjects was 31 years (range 18 to 54), the mean weight was 66 kg (range 45.5 to 82.7), and the level of injury was from T4 to C3. Following the infusion peak, to-

bramycin in serum concentration averaged 3.4 ± 0.8 g/ml. At the end of the 8-hour dosing interval, trough levels averaged 0.3 ± 0.2 g/ml.

In the 18 subjects studied, the mean half life of tobramycin was 113 minutes. The serum clearance (CI) averaged 147 ± 40 ml/min or 23.5 ± 7.3 liters or 0.36 ± 0.10 .

Preliminary Results—The data in the limited population studied strongly suggest that the disposition of tobramycin in persons with SCI may be quite different from the disposition in people with intact spinal cords. Both the volume distribution (V_{ss}) and clearance appear to be higher in SCI. Data published for tobramycin in the intact spinal cord subject indicate

average clearance values of approximately 1.87 ml/min/kg and a mean volume of distribution of 0.26 l/kg. The physiological basis for the differences is not known, but these data suggest that dosages of tobramycin in patients with SCI requiring aminoglycoside therapy may have to be increased to provide serum concentrations to adequately cover susceptible organisms. Trough serum tobramycin concentrations were <0.30 μ g/ml. If one assumes that trough tobramycin serum levels should be approximately 1 μ g/ml, we found that in our study population the aminoglycoside concentration falls below this level at 4 hours post-dosing. Thus, a change in tobramycin dosage regimen in SCI patients would be appropriate.

Mechanism of Active Expiration in Tetraplegic Subjects

Andre de Troyer, M.D.; Marc Estenne, M.D., Ph.D.; Andre Heilporn, M.D.
Brussels School of Medicine, Erasme University Hospital, 1070 Brussels, Belgium
Sponsor: None listed

Purpose—Traumatic tetraplegia produces paralysis of all the well-recognized muscles of expiration. Yet, tetraplegic subjects usually have a small expiratory reserve volume on spirographic examination.

Progress—To understand the mechanism that enables these patients to empty their lungs actively, we studied the pattern of chest-wall motion during voluntary expiration. We found negligible changes in abdominal dimension, but all subjects had a marked and reproducible decrease in the dimension of the upper rib cage. Electrical measurements established that the

subjects had active use of the clavicular portion of the *pectoralis major*, and changing the orientation of these muscle fibers by maintaining the shoulders in abduction reduced their expiratory reserve volume by about 60 percent ($P > 0.001$). We, therefore, conclude that the clavicular portion of the pectoralis major plays a crucial part in the mechanism of active expiration in tetraplegic subjects. Training of this muscle bundle could, by increasing its strength and endurance, improve the effectiveness of coughing in such subjects and perhaps diminish the prevalence of bronchopulmonary infections.

Evaluation and Rehabilitation of Reproductive Function in Paraplegia

Inder Perkash, M.D. and David E. Martin, Ph.D.
Veterans Administration Medical Center, Palo Alto, CA 94304 and Yerkes Primate Research Center, Atlanta, GA 30030
Sponsor: VA Rehabilitation Research and Development Service

Purpose—This is an interdisciplinary effort in urology, physiology, biomedical engineering, and rehabilitation medicine. Earlier work focused on the development of rectal probe electrostimulation (RPE) from a trial research

mode into a state of clinical feasibility for routine evaluation of patients regarding production of erections and seminal emissions. Continued recent work has been directed at antegrade semen collection, with evaluation of semen

quality and the possible use of acceptable specimens in artificial insemination of the patient's mate. Efforts also will be directed at further refinement of RPE instrumentation to a device appropriate for use by the patient and his mate in their home, to produce erections and, if antegrade ejaculation could occur, to allow for insemination.

Progress—Although patients with injury level between T2 and L3 are being studied, results thus far with nearly 50 patients suggest that RPE can be of greatest benefit to those with injury levels between T5 and T12. Those with injury level lower than T12 often have too much remaining sensorium to tolerate current delivery, while those with injury higher than T5 have an increased risk of RPE-induced autonomic dysreflexia.

Patients volunteering for study fit into three categories: those primarily interested in achieving antegrade ejaculation of semen of sufficient quality that artificial insemination of their mate is appropriate; those interested essentially in obtaining or improving the quality of erection; and those interested in both.

For those patients desirous of siring children, the timing of RPE to coincide optimally with the ovulation period of their mate is rather simple. Less easy has been the improvement of sperm motility, which generally is quite low (typically less than 15 percent progressive motility is observed). In some instances sperm motility has been improved simply by minimizing contamination with bladder urine. This has involved Foley catheterization to prevent retrograde semen flow, with optimum balloon inflation volume and placement deter-

mined in part by urodynamic studies and transrectal urethral sonography. In other instances, for whom retrograde ejaculation cannot be prevented, pre-RPE irrigation of the bladder with a solution of 90 percent Ringers Lactate and 10 percent sodium bicarbonate serves to maintain urine pH at a favorable level (7.2-7.4) for sperm survival until retrieval and transfer to a more appropriate medium.

Insemination of one such semen specimen, consisting of approximately 164 million sperm with 51 percent sperm motility, collected from a T11 paraplegic and transferred to his mate using a cervical cap, resulted in a pregnancy, with eventual delivery of a healthy male infant. In the majority of cases, however, for reasons not yet identified, sperm motility remains consistently quite low. Refinement of RPE instrumentation to permit more frequent and routine semen collection is allowing useful pursuit of this problem.

In addition to the electrical-outlet-operated stimulator, we are now designing and constructing an RPE device appropriate for use by the patient and spouse in the home. Other workers in the field have envisioned such a device, particularly for patients who are able to produce erections and antegrade semen emissions using RPE. This could permit such couples to achieve a more functional sexual relationship in a private setting.

A detailed analysis of both safety constraints and patient needs has been completed, and all electronic circuitry has been designed. Construction of the first unit will be completed and clinical testing will be initiated during the next year of funding.

A Feasibility Study on Detection of Impending Pressure Sores Using Ultrasound

G. V. B. Cochran, M.D., M.Sc.D. and Murali P. Kadaba, Ph.D.

Helen Hayes Hospital, West Haverstraw, NY 10993 and Veterans Administration Medical Center, Surgical Research Service, Castle Point, NY 12511

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Pressure sores are a major complication for spinal cord injured and certain other disabled persons. Frequently these areas of

tissue breakdown begin deep in pressure sensitive areas of muscle tissue and cannot be detected clinically until the process has become

irreversible. The objective of our current study is to develop ultrasonic techniques (measurements of attenuation and backscattering) that are capable of assessing the state of deep muscle tissues with respect to early changes signaling the incipient development of muscle necrosis.

The proposed research will approach this problem by means of our established experimental model in pigs. Tissue damage in the animals is created by applying a constant force, over a period of hours, through specially shaped indentors under the control of a microprocessor. This technique is being employed to create a known degree of tissue damage on which specific acoustic parameters can be measured for comparison to normal.

Preliminary Results—Initial tests have confirmed that when a critical time-pressure parameter is exceeded, necrosis of tissue takes

place. Our preliminary studies clearly show that the deep muscle tissues are more sensitive than skin to pressure effects and that the type of decubitus ulcer that results from direct pressure (rather than superficial shear) begins in the deep muscle layer. In fact, muscle necrosis in our model is usually seen in the absence of permanent skin damage. Our work now in progress involves correlation of acoustic parameters with histology of pressure damaged tissues. These measurements will lay the groundwork for future development of clinical testing apparatus and procedures.

Future Plans—If this feasibility study is successful, it will lead to a clinically usable ultrasonic scanning test that can warn of impending pressure sores at the preclinical stage, in time to take corrective action to permit healing before tissue necrosis occurs.

Skin Deformation and Blood Flow Under External Loading

Alvin H. Sacks, Ph.D.; Inder Perakash, M.D.; Hugh O'Neill, B.S.

Rehabilitation Research and Development Center Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor:—*Veterans Administration Rehabilitation Research and Development Service*

Purpose:—Spinal cord injury patients are known to be more prone to the development of pressure sores than are able-bodied individuals because of the loss of mobility and sensation. But within the SCI population, some patients are significantly more prone to such problems than others, and the reasons for these differences are not known.

Since the initiation of pressure sores is known to be associated with a compromise of skin blood flow, this investigation is directed toward the measurement of skin blood flow response to controlled external pressure loading in spinal cord injury patients. If there are indeed differences in skin blood flow response to loading which can be easily measured, then it may be possible to identify those patients who are more susceptible to pressure sores upon admission to the hospital. That would permit a shifting of nursing care in such a manner as to diminish the incidence of pres-

sure sores in VA hospitals. At the present time, the average cost per patient of treatment for pressure sores is in the vicinity of \$15,000 to \$25,000 per year, not to mention the cost in patient discomfort and loss of time. A method of identifying patients at risk could be most valuable in diminishing these costs.

There have been a limited number of studies in which skin blood flow under external loading has been measured by a number of different techniques, all of which have involved rather indirect methods. The findings of such investigations have shown that there is generally a decrease in skin blood flow with loading, and although there seems to be considerable variation in the quantitative results, blood flow in the skin apparently ceases at a local pressure loading of about 100 mm Hg in able-bodied young subjects.

These occlusive pressures are evidently much lower in older and in paralyzed subjects,

but the large variability of the curves of skin blood flow versus pressure makes it difficult to draw any meaningful conclusions.

The present study differs from previous studies in two major respects. The first of these is that a dimensional analysis is carried out to insure that all of the necessary quantities are measured and are treated in the appropriate nondimensional forms to give meaningful results. The second is that a new noninvasive technique is used for the direct measurement of skin blood flow. We are attempting to make full use of newly available noninvasive laser doppler flow meter (LD 5000, MedPacific, Seattle) which is claimed to make continuous measurements of skin blood flow. Some information on use of this instrument is contained in this report.

Measurements of skin blood flow response to loading in able-bodied subjects and in spinal cord patients who do and do not have a continuing problem with pressure sores are first made on the proximal femur in the side-lying position, for ease of measurement and accessibility, and then on the ischial tuberosities with the subject bent over a table, in order to apply controlled loads in a known fashion.

Dimensional analysis is used to determine the appropriate nondimensional forms of the most important parameters.

Progress—The dimensional analysis has been completed. It shows that the ratio of skin blood flow to baseline flow (at no load) is a function of only two nondimensional quantities: the ratio of skin indentation to bone depth, and the ratio of bone depth to the diameter of the cylindrical indenter. Therefore, we are measuring the bone depth on each subject, as well as the

skin indentation at each loading.

Bone depth is measured using echo doppler equipment, and indentation is obtained, for the femur measurements, from the vertical displacement of the loading weights at each load. These measurements are not usually made in such studies, but are felt to be essential to proper interpretation of the results. The dimensional analysis also shows that it is not necessary to measure the applied pressure. However, pressure measurements are now being incorporated in order to facilitate comparisons with previous studies.

Displacement measurements on four subjects have indicated that the "stiffness" of the tissues increases systematically, regardless of injury. It can be seen that:

- 1) The elastic behavior of the tissues is in all cases nonlinear, with the tissues getting stiffer as the load increases; and
- 2) The required load for a given displacement increases with age.

Early measurements on able-bodied and spinal cord injured subjects have shown that the laser doppler does not accurately measure blood flow at high loadings because the skin blood flow is sufficiently decreased that artifacts become important. That is, the laser doppler is exquisitely sensitive to all motion to such a degree that random red-cell motion, due to temperature or to individual red cell interaction, is responsible for a significant portion of the doppler signal. Therefore, the method of loading by adding weights to a platform has been modified to use a precision micrometer technique for applying known small indentations to the skin. (The doppler will now be used at low loadings, where the artifacts should become insignificant.)

Biochemical Analysis of Sweat as an Indicator of Tissue Viability

Martin W. Ferguson-Pell, Ph.D. and S. Hagusawa

Helen Hayes Hospital, West Haverstraw, NY 10993; School of Nursing, Kumamoto University, Kumamoto, Japan

Sponsor: New York State Department of Health

Purpose—A simple method for early detection of pressure sores has been elusive. Measurements of tissue pO_2 , skin temperature, mechan-

ical indentation properties of soft tissue, blood flow rate and ultrasonic properties are under investigation at various centers. Biochemical

changes have attracted less interest as their detection would normally require invasive sampling of tissue fluids. In this study, we are investigating the potential of measuring changes in sweat biochemistry to determine whether substances generated during ischemia or in the early stages of trauma can be detected. If successful, this approach will offer the potential for early identification of areas of tissue in distress. Lactate acid production is one biochemical factor in sweat that responds to periods of ischemia. Lactic acid is a by-product of anaerobic glycolysis of the sweat gland and its concentration in sweat increases during ischemia. One early previous study has demonstrated this effect for whole limb ischemia and our present work is investigating the relationship between lactate concentration and localized ischemia history. Na^+ concentration in sweat is also modified by ischemia and parallel studies for

Na^+ and Ca_2^{++} are also underway.

Progress—Protocols for this study are established and preliminary data has been collected. Sweating is induced using iontophoresis of pilocarpine nitrate and collected using the Macroduct system (Westcor) used for cystic fibrosis screening. Sensitive assays for sodium, calcium and lactate have been established allowing accurate measurement of these substances from less than 20 μl of sweat. Preliminary data are inconclusive, sweat having been collected during the reactive hyperemia stage post-ischemia. Work is now in progress to confirm these results and to measure lactate, Na^+ , Ca_2^{++} concentrations during application of ischemia. Investigation is also in progress to measure biochemicals such as histamine that are indicative of inflammatory responses associated with the early stages of tissue breakdown.

C. Spinal Cord Regeneration

An *In Vivo* Model to Assess the Neurotrophic Function of Mammalian CNS Glia _____

Gary D. Kukes, M.D., Ph.D

Veterans Administration Medical Center, Long Beach CA 90822

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation*

Purpose—Severe injury to the mammalian spinal cord usually results in permanent loss of morphologic integrity and neurologic function. In some lower animals such as fish and amphibians complete regeneration of the spinal cord does occur. Based on the central role of ependymoglia cells in guiding axons during regeneration in these lower forms and a similar function proposed for nerve cell guidance by radial glial cells in the developing mammalian cerebellum, it is thought that certain glial surface properties or secreted trophic molecules underlie these neuron-glia interactions.

It was hypothesized that because of the specific developmental timeframe during which glial cells appear to positively influence neurite outgrowth and directionality, the capacity of

glia to induce these neural responses is a function of the age and degree of differentiation of the glial cells. If "permissive" glial cells were found, for example, in the vicinity of severed axons in the injured mammalian spinal cord, the regenerative response might be significantly enhanced.

Progress—To test this hypothesis, small cavities were made in the adult rat spinal cord into which were implanted three different types of central nervous system glial preparations. These included embryonic rat glial cells from the presumptive *corpus callosum*, pure populations of neonatal rat cerebral astrocytes, and mature rat astrocytes from degenerative optic nerve. The degree and extent to which host

cord neurites penetrate each type of cellular graft was quantitated by individual fiber measurements made microscopically on specially stained histologic sections prepared from ani-

mals sacrificed at various intervals post-transplant. These results are being compared to control grafts implanted with either rat embryonic cortex or no cells.

Plasticity in the Injured and Aging Mammalian Spinal Cord

Harry G. Goshgarian, Ph.D.

Wayne State University, Detroit, MI 48202

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation*

Purpose—The research is aimed at substantiating the relationship between specific morphologic changes in the phrenic nucleus that occur within hours of spinal cord insult with the functional recovery of a portion of the paralyzed hemidiaphragm.

Progress—Our first task was to morphologically characterize and quantitate at the electron microscopic level the unique neuronal, synaptic, and glial alterations that have been observed in the phrenic nucleus within hours after spinal cord injury in the rat. Significant progress has been made toward realizing this objective. All of the normal young adult rat tissue has been processed and most of it has been analyzed by the computer. In addition, all the normal older adult rats have been sacrificed and at least three-quarters of the material have been analyzed by the computer.

Preliminary Results—The original hypothesis seems to have been correct. Qualitative results show that the rapid morphologic changes induced by the spinal cord injury in the young adult rat also were seen in the normal spinal

cord of the older rat. Thus, it seems that the rapid changes that occur in injury also occur slowly and progressively in the normal spinal cord as a consequence of aging.

The research has progressed to where we can prepare highly purified neonatal glial preparations consisting of 79 percent astrocytes. The astrocytic origin of these cells has been confirmed by electron microscopy. These cells and embryonic glial cells will serve as donor cell preparations to introduce into transplantation cavities in the adult rat spinal cord.

We have experimented with a number of techniques to introduce astrocytes into the spinal cord, and are now using microsurgical techniques with cutting scissors and a microknife to sever axons in the corticospinal tract, then implanting the donor cells by means of microspatula.

Future Plans—A series of future experiments will use neonatal and embryonic glial cells to test their efforts on the maintenance of severed corticospinal fibers and on sprouting and regenerating these fibers.

A Study of Phosphoprotein in a Regenerating CNS Tract

Denis Larrivee, Ph.D.

Cornell University Medical Center, New York, NY 10021

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation and the National Spinal Cord Injury Association*

Purpose—The overall objective is to identify specific molecules that regulate regeneration and to understand how these molecules carry out their functions. Protein phosphorylation

events associated specifically with the regenerative process will be investigated by identifying differences in the amount of phosphate incorporated into individual proteins: 1) between re-

generating and normal neurons; 2) under conditions modifying distinct phases of regeneration; and 3) with application of agents that retard or enhance regeneration. In addition, an attempt will be made to determine in each case whether phosphate incorporation is directly coupled to protein synthesis or to a subsequent modifica-

tion of the protein inside the cell body or its axon, and to define the location of the phosphorylating system. These experiments will be conducted on the goldfish optic nerve, which has demonstrated the capability for extremely vigorous regeneration.

Spinal Cord Regeneration of Descending Locomotor Command Systems in a Lower Vertebrate, the Lamprey

Andrew D. McClellan, Ph.D.

University of Iowa, Ames, IA 50011

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation and National Spinal Cord Injury Association*

Purpose—This research deals with the function and regenerative capacity of the locomotor command system in the brainstem of a lower vertebrate, the lamprey. The transected spinal cords of lampreys, unlike those of most other vertebrates, regenerate significantly, which results in almost complete recovery of motor function. In addition, it is possible to place the isolated lamprey nervous system in a recording chamber, which will remain alive and generate the motor pattern for locomotion.

The three aims of this research are: 1) to determine the locations of the descending brainstem command neurons that project to the spinal cord and activate locomotor patterns, using two complimentary methods—an anatomical tract-tracing using horseradish peroxidase,

and a chemical stimulation technique using iontophoresis of excitatory amino acids to activate small groups of neurons in specific areas of the brainstem; 2) to determine the anatomical and physiological properties of the brainstem command neurons for locomotion from data accumulated on the biophysical properties, activity patterns, and morphology of brainstem neurons; and 3) to examine the mechanisms that account for behavioral recovery after spinal cord injury in the lamprey, and the properties of brainstem command neurons and their connection to spinal cord cells after regeneration. Intracellular and extracellular recording from an *in vitro* system preparation will be used, which will generate locomotor patterns similar to those observed in intact animals.

Fetal Spinal Cord Transplantation into the Chronically Injured Rat Spinal Cord

John D. Houle, Ph.D.

University of Florida, College of Medicine, Gainesville, FL 33610

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation and National Spinal Cord Injury Association*

Purpose—This research specifically addresses the issue of regeneration in the chronically injured spinal cord. The immediate objectives are: 1) to examine how the special biological problems related to the advanced histopathological changes in the host cord affect various parameters of fetal CNS tissue grafting; and 2) to develop an experimental transplantation strategy that applies to situations similar to those found in human injury.

The first goal is to determine the survival and developmental characteristics of fetal spinal cord implants when placed into the original lesion site. The second goal is to explore whether axonal interactions between host and graft can be augmented after transplantation into the chronically injured spinal cord. The third goal is to determine the efficacy of fetal tissue transplantation into contusion lesions of the adult spinal cord.

Thus, these studies address several fundamental issues related to intraspinal transplan-

tation as a means for ultimately stimulating functional recovery in the injured spinal cord.

Study to Determine if Localized Extracellular Proteolysis Is a Requirement for Successful Regeneration of Nervous Tissue

Nurit Kalderon, Ph.D.

The Rockefeller University, New York, NY 10021

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation and National Spinal Cord Injury Association*

Purpose—It is the working hypothesis of this research that proteolytic activity is an essential process in repairing a damaged nervous system. However, proteolytic activity must be localized rather than general or random. General injection of these enzymes can lead to uncontrolled tissue destruction, whereas localized proteolysis, e.g., a plasmin-generating system expressed by the cell in a highly controlled manner, will remove only the unwanted tissue in the path of the regenerating axons. To assess this hypothesis, two model systems of regenerating nervous systems will be used: peripheral, i.e., sciatic nerve; and central, i.e., the olfactory bulb, with regeneration induced by various grafts into it. Assuming that localized proteolysis is essential for regeneration, any treatment or cell type

(e.g., mature astrocyte) that inhibits this activity should intervene and prevent the regenerating process. On the other hand, any other cell type that is known to produce this specific proteolytic activity, i.e., premature astrocyte and tumor cell lines, should support neuronal regeneration when implanted in the injured tissue.

Future Plans—If this hypothesis is verified, novel avenues will be opened for research into possible therapeutic procedures to induce repair and/or recovery in any injured nervous system. One of these could be the development of a device to apply these proteolytic enzymes of the plasmin-generating system in a localized manner at the locus of injury.

Axon Regeneration in the Mammalian Spinal Cord in Response to Surgical Denervation and Nerve Growth Factor

Claire E. Hulsebosch, Ph.D.

Marine Biomedical Institute, University of Texas Medical Branch, Galveston, TX 77553

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation and National Spinal Cord Injury Association*

Progress—Sensory nerve cells entering the spinal cord travel in the dorsal root and convey information such as touch, pressure, heat, and pain to the central nervous system. The sensory cells that carry information from the periphery to the spinal cord have their cell bodies in the dorsal root ganglion (DRG) outside of the spinal cord. There are two categories of nerve processes that these nerve cells send into the spinal cord: 1) unmyelinated axons; and 2) myelinated axons. These axons travel in the dorsal root and enter the spinal cord to make many synapses (or specialized contacts) on nerve cells in the cord.

Preliminary Results—Unless sprouting can be quantitated, it is not possible to determine accurately the parameters of this phenomenon. The electron microscope is being used to count the numbers of myelinated and unmyelinated axons in the dorsal roots and spinal tracts of rats that are subjected to spinal cord or dorsal root injury on one side. The normal side of the animal is compared to the injured side so that each animal serves as its own control. In these experiments, the number of axons in the dorsal roots on the injured side was 15 to 20 percent greater than the number on the normal side. Furthermore, the increase was in the unmye-

linated axon population and not the myelinated axon population. This increase was apparent for some distance cranial and caudal to the surgery. Since sprouting results in an increase in axon number, these results indicate that sensory axons sprout in response to spinal cord denervation. Other work in the laboratory indicates that neurons of younger mammals sprout more vigorously than older animals.

The next step is to determine if the sensory sprouting can be manipulated by a growth factor. Nerve growth factor (NGF) is being studied because this protein is well characterized; can be purified in stable form; and most importantly, has been shown to stimulate sprouting of sensory neurons in culture. Questions asked specifically relate to the NGF affecting the number of nerve cells and/or nerve processes in the uninjured mammal and the injured mammal. Data now indicate that NGF is involved in the sprouting of sensory axons.

Rats, spinal cord injured on one side, were divided into three groups: the first received NGF; the second received rabbit whole sera; and the third rabbit whole sera that included antibodies against NGF. All groups received daily doses for a 1-month-period. After this period, rats were sacrificed and the number of axons in dorsal roots from the injured side were counted and compared to counts from the other side as a control. The first two groups of rats confirmed results from the previous study of rats that were spinal cord injured with no additional treatment: the number of unmyelinated axons is greater in dorsal roots of the injured side as compared to the control side. However, in the third group of rats, who had been receiv-

ing antibodies against NGF, the number of unmyelinated axons in the dorsal roots on the control side was greater by about 20 percent than the increased number observed on the hemisected side. This increase indicates that the nerve cells on the control side sprouted more vigorously than those on the injured side.

Preliminary Results—Nerve growth factor is important in maintaining the nerve supply to a tissue. The tissue synthesizes molecules of NGF, which the nerve processes transport back to the nerve cell nucleus. Then, the transported NGF acts to "inform" the nerve cell that it is innervating the correct tissue. Any cessation in this process is a removal of the innervated tissue and/or damage to the nerve processes. If the antibodies to NGF (anti-NGF) are introduced to the animal, the anti-NGF binds itself to NGF and biologically inactivates the NGF molecules. The nerve cells can no longer receive their NGF information and are fooled into believing that the tissue or their processes have been removed. This phenomenon can be called "chemical denervation."

In the group of rats with hemisected cords given the antibody to NGF, only the hemisected side of the cord was surgically denervated, and both sides were chemically denervated. Dorsal root axons, chemically denervated on the control side, sprouted more vigorously than those on the surgically denervated side. (The trauma of surgery may inhibit some of the sprouting potential.) More recent experiments support that exposing rats to the antibodies to NGF with no surgical manipulation will produce vigorous sensory neuron sprouting.

Axonal Regeneration in the Adult Spinal Cord

Francis J. Liuzzi, Ph.D.

Case Western Reserve University, Cleveland, OH 44106

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation*

Progress—HRP anterograde injury-filling has been used to study the regeneration of axons into and within the adult spinal cord. These studies have examined the use of frog spinal cord as a model to look at axonal regeneration

within the central nervous system (CNS). It is possible to introduce three different kinds of axons into the spinal cord: 1) the central branch of dorsal root ganglion cells; 2) the peripheral branch of dorsal root ganglion cells;

and 3) axons of ventral motoneurons. This experimental model can be used to compare the regeneration of three very different populations of axons within the same region of the CNS, and may provide information about the intrinsic differences between the growth potential.

Future Plans—The study will: 1) further define the regions of the frog spinal cord that support or do not support axonal growth, by completing electron microscopic analyses of the regeneration of dorsal root axons; 2) determine, at the electron microscopic level, what cellular elements act as a substrate to axonal growth; and 3) compare the regeneration of the three populations of axons within the white and gray matter of the spinal cord in frogs.

The second goal of this project is to study, at the light and electron microscopic level, the regeneration of dorsal root axons in the rat. The objectives are to: 1) determine the percentage of dorsal root axons that regenerate into the rat spinal cord; 2) define the regions of the rat spinal cord that support or do not support

axonal growth by carefully mapping the growth of the axons; 3) determine, at the electron microscopic level, what cellular elements act as a substrate for axonal growth in the rat spinal cord by identifying those cellular elements that are most frequently contacted by axons that have regenerated well; and 4) examine, at the electron microscopic level, the reactive glia barrier at the root transitional zone.

Immunohistochemical studies of the astrocytes in the frog and rat spinal cords will define the types of astrocytes in the normal spinal cords of the two species and determine the identity of the astrocytes that become reactive after dorsal root trauma in the two species. The long-term goal of this research is to use the frog spinal cord as a model of spinal cord regeneration in which to define whether neuronal and environmental factors sustain or constrain regeneration.

Furthermore, this research will identify similarities and differences in the regeneration of axons in the frog and rat spinal cord.

Recovery of Function and Anatomical Repair After Spinal Cord Transections in Newborn and Adult Rats

Barbara S. Bregman, Ph.D.

University of Maryland School of Medicine, Baltimore, MD 21201

Sponsor: Paralyzed Veterans of America Spinal Cord Research Foundation

Purpose—The goal of this project is to determine whether neural tissue transplants of fetal spinal cord tissue can promote anatomical repair and mediate recovery of function after spinal cord transections in newborn and adult rats. Neural tissue may be able to restore motor function after spinal cord lesions, either by providing a bridge for axons to cross the gap created by the lesion, or by providing a pool of neurons that can serve as a relay for descending supraspinal input to reach caudal spinal levels. Neuroanatomical tracing techniques are being used to assess the anatomical repair of the injured spinal cord and quantitative behavioral analysis of locomotion, postural reflexes, and bladder reflexes to assess the effect of transplants in recovery of function.

Progress—Segments of immature spinal cord tissue from rat fetuses are being implanted into the lesion sites of adult rat spinal cords at a mid-thoracic level. Anatomical examination of the tissue by light and electron microscopy 1 month to 1 year later indicates that the transplants survive, grow, and mature. There are many areas in which the host spinal cord and the transplants are in direct opposition without any intervening gap or barrier. The transplants contain many mature nerve cells, fibers, and synapses. Experiments indicate that some nerve cells located within the transplants send their axons into the host spinal cord and conversely, some nerve cells in the host spinal cord, send axons into the transplant. The growth of axons appears to be greater after le-

sions made in young animals than in the adult animals. It is known that there is substantial recovery of function and anatomical reorganization following partial spinal cord lesions in newborn and adult mammals. Even following complete spinal cord lesions, the spinal cord possesses some innate capacity for eliciting locomotor patterns (spinal pattern generator for locomotion). However, this motor function of the isolated spinal cord is sufficient to allow stereotyped movement only.

The older the animal is at the time of transection, the poorer the quality of the spinal motor function. Indicative is a decline in autonomous spinal motor function occurring during normal development. During post-natal development, locomotor behavior becomes dependent upon supraspinal control. Spinal cord transection permanently removes that supraspinal control, and spinal motor function reemerges. A similar decline in the innate capacity of the spinal cord to elicit movement occurs during phylogenetic development, since spinal monkeys and humans do not display spinal locomotion, but rats, cats, and dogs do display considerable spinal locomotion. Similarly, bladder

function is mediated at a spinal cord level early during post-natal development, but later becomes dependent upon supraspinal control, which is characteristic of the adult. Spinal cord transection results in the permanent loss of this supraspinal control of micturition, and the spinal reflex reemerges.

The aim of this research is to determine whether neural tissue transplants of fetal spinal cord tissue can reestablish anatomical pathways that allow recovery of supraspinal control of locomotor and bladder function. Neural tissue transplantation techniques are being used as tools to better understand the response of the immature and mature central nervous system in terms of damaging and identifying the anatomical and functional processes involved in the repair of the injured spinal cord. The pattern of growth of fibers in newborn and adult, and the pattern and density of innervation in the host spinal cord caudal to the transplant, seen normally, will be compared. In the normal animal, the spinal locomotor generator can be modified by descending supraspinal control.

Development and Regeneration of Afferent Motoneuron Contacts in Rat Embryos _____

Lea Ziskind-Conhaim, Ph.D.

University of Wisconsin, Madison, WI 54301

Sponsor: *Paralyzed Veterans of America Spinal Cord Research Foundation*

Purpose—This project will study the inductive interaction between sensory and motor neurons and the specificity of their initial interactions. Some of the experiments will be carried out in organ culture where the environment of the developing neuronal circuits can be controlled. Segments of body wall, including intercostal muscles, ribs, and spinal cord will be explanted from 14-day to 18-day embryonic rats (birth is at 22 days of gestation) and maintained in organ culture for up to 6 days. In this preparation the normal geometric and mechanical relationships of spinal cord and muscle can be retained during the culturing procedure. The intercostal nerve-muscle contacts develop in organ culture with a pattern and time course

similar to their development in a living rat.

Our investigation will also: 1) record electrical signals in motoneurons and determine the changes in these signals during the formation of sensory contacts with them and record sensory inputs on the pharmacological properties of immature motoneurons; 2) study the effects of peripheral nerve cut close to the muscle and the effects of lesions of sensory nerves on the electrical and pharmacological properties of motoneurons; 3) investigate the regenerative ability of lesioned sensory axons to contact their target motoneurons (using both morphological and electrophysiological techniques); and 4) study the regrowth of sensory nerves using a dye that is carried in axons and marks their lo-

cation in the spinal cord. Mature mammalian-cut axons in the central nervous system regenerate to only short distances, and, unlike peripheral nerves, do not grow back to innervate their appropriate target. Functional regeneration of sensory nerves will be assessed by stimulating them and recording electrical signals in

the motoneurons that they innervate. Our understanding of the functional development of neuronal circuits and their inductive relationships is essential for approaching the important goal of manipulating the regenerative abilities of the adult central nervous system.

Evaluation of a Novel Spinal Cord Injury Model

James M. Cullen, Ph.D.

The Research Foundation of State University of New York, Albany, NY 12201

Sponsor: Paralyzed Veterans of America Spinal Cord Research Foundation

Progress—This research was first designed to test the innate capacity of spinal cord fibers to regrow when left with a matrix of viable central nervous system tissue connecting cut segments of the cord, and second, to stimulate nerve fiber regrowth using low-level electrical current applied to the injury.

Progress—To accomplish the first, a spinal cord injury model was developed in which separate cuts were made in opposite sides of the cord at two different levels at midspine. All long fiber tracts extending between the brain and the spinal cord were interrupted, but an undisturbed mass of spinal cord tissue was preserved

between lesions. This arrangement induces a paraplegic condition while maintaining a CNS connection between damaged cord ends that act as a conduit for regrowing nerve fibers.

The next step will be to stimulate the regenerative process by electricity, by implanting fine multi-stranded platinum electrodes near the damaged region. The electrodes will be connected to a small, battery-powered cell placed under the skin of the lower back. Results from these studies will provide important clues to answering two questions: 1) What is the potential for nerve fiber growth? 2) Can electrical intervention support a regenerative effort?

Spinal Cord Explants Cultured on Carbon Filaments and Stimulated with Direct Current

Talat A. Khan, Ph.D.

Veterans Administration Medical Center, Hines, IL 60141

Sponsor: Paralyzed Veterans of America, Vaughan Chapter

Purpose—Following complete spinal cord transection in mammals, nerve fibers above the transection begin to regrow. It has been thought that the environment at the site of the injury was unfavorable to growing and regenerating axons. Many investigators have attempted to modify the microenvironment to make it more favorable to nerve fiber regrowth. One of the methods has been to stimulate regrowth with minute electric currents. However, the process of axonal regeneration alone is not sufficient for functional recovery. The growing

axons must be guided and directed to their proper destination.

A few laboratories have reported successful implants of carbon filaments as substitutes for injured ligaments and tendons, in both experimental and clinical studies. Carbon filaments provide mechanical strength and act as a scaffold for the development of new aligned fibrous tissue. The filaments eventually degrade as the new tissue matures. This study was designed to evaluate the influence of carbon filaments on the growth and orientation of nerve fibers from

spinal cord explants *in vitro*. For this study we designed a petri dish in which we attached approximately 3000 carbon filaments (8-10 mm diameter) to the bottom of the dish with their free ends extending through and beyond the dish. We then sterilized the entire assembly. We placed spinal cord explants on the carbon filaments, with the free ends of the filaments attached to a 0.2-milliamperere direct-current source. We prepared spinal cord explants consisting of 1-2-mm-thick thoracolumbar cord segments from 15-day to 17-day-old rat embryos under sterile conditions. All explants were grown for 3 weeks in Dulbecco's modification of Eagles' medium, supplemented with fetal calf serum, glucose, and penicillin-streptomycin at 37 degrees C in a humidified 95 percent air and 5 percent CO₂ atmosphere. At the end of 3 weeks, we rinsed all culture dishes with physiological saline. Using an ocular micrometer, we

measured fibrous outgrowth from the edge of the explant to its most distal point. We observed healthy explants after 3 weeks in culture. A scanning electron microscope (SEM) showed us that outgrowth from explants was parallel to the longitudinal axis of the carbon filaments. Neurites from the explants were growing on and in between the carbon filaments. The outgrowth we observed with SEM appeared to be both nerve fibers (when stained with silver protargol method) and glial fibers (when stained with immunoperoxidase method). In electrically stimulated explants, neurite length was greater towards the negative pole. We believe that the carbon filaments provide support and guidance for the growing fibers from the spinal cord explants in tissue culture. A 0.2-milliamperere constant current, when passed through the carbon filaments, enhanced fiber growth.

Influence of Continuous Electrical Stimulation On the Spinal Cord Motor Neurons _____

Talat A. Khan, Ph.D.

Veterans Administration Medical Center, Hines, IL 60141

Sponsor: Paralyzed Veterans of America, Vaughan Chapter

Progress—Applied electric fields have been reported to facilitate regeneration or regrowth of injured peripheral nerves and severed spinal cord axons. We are conducting this study to evaluate what stimulation parameters might be best. For the study we anesthetized female Wistar rats, 200-250 gm in weight, with 6 percent chloral hydrate, then performed laminectomies to expose T10-T13 levels of the spinal cord. We inserted tantalum electrodes into the cords at a depth of 1 mm and spaced 2 cm apart, with the current traveling in a head-to-foot direction. The stimulator was sutured subcutaneously. For stimulation we used monophasic pulses of 130 mV, 0.3 millisecond duration 120 milliseconds apart. After 3 months of continuous stimulation, we sacrificed all animals by perfusion with Karnovsky's fixative, then removed the spinal cords, cut them into small pieces, and processed them for the electron mi-

croscopic examination. After 3 months of continuous electrical stimulation, the animals did not exhibit any motor deficits upon gross observation; they appeared normal in all respects. However, when they were allowed to walk on a smooth surface, such as X-ray film, their hind limbs showed a slight deficit in grabbing as compared to non-stimulated animals. We also noted some tissue disruption of the spinal cord at the site of anodal electrode insertion. Our electron microscopic examination of motor neurons located between the two electrodes and below the cathode showed typical-appearing neurons, glia, and synaptic structures. However, upon further observation, we noted an alteration in the stacking of individual strands of rough endoplasmic reticulum and the distribution and quantity of Nissl substance of the motor neurons.

D. Independent Living for the Severely Disabled

Parameters of Independent Living Programs: A Longitudinal Study

Margaret A. Nosek, Ph.D.

Baylor College of Medicine and ILRU Research and Training Center on Independent Living at TIRR, Houston, TX 77225

Sponsor: *National Institute of Handicapped Research*

Purpose—This study builds on three previous comprehensive descriptive studies of independent living programs conducted by ILRU over the past nine years. The purpose is to maintain a database on the status of independent living programs nationally and through analysis, identify trends in their development, the emergence of new problems and new solutions for the delivery of independent living services, and changes in the characteristics of consumers of these services.

Progress—The survey used in previous studies by ILRU has been revised and refined using input received from senior project consultants. It has been pilot tested and further refined. The survey instrument is being mailed to each of the more than 300 programs listed in the ILRU Directory of Independent Living Programs, and to directors of state vocational rehabilitation agencies and the 10 regional offices of the Rehabilitation Services Administration for referral to programs not included in the ILRU list. Information will be solicited concerning

populations served, services provided, characteristics of persons providing services, methods by which services are provided and program is administered, sources of funding, and relationships between programs and their community. Data will be coded and entered into the computer for univariate and multivariate analyses. Results will be presented and discussed in a new edition of the ILRU Registry of Independent Living Programs. The survey will be repeated annually.

The existing database is being updated as new information is obtained. A directory listing all identified independent living programs is revised on an on-going basis and is disseminated widely. The registry of independent living programs developed from the previous survey is also available. The ILRU Research and Training Center on Independent Living at TIRR is continuing its networking, training, and technical assistance activities using these data for the benefit of any independent living program or individual interested in independent living.

Independent Living in Rural Areas: A Longitudinal Study

Margaret A. Nosek, Ph.D.

Baylor College of Medicine and ILRU Research and Training Center on Independent Living at TIRR, Houston, TX 77225

Sponsor: *National Institute of Handicapped Research*

Purpose—Under a 3-year grant from NIHR, ILRU recently completed a project to expand independent living opportunities for disabled residents of rural areas. Six demonstration sites were established and given ongoing support until the project was completed in April of 1986. The current Research and Training Center project is designed to examine the long-

term effects of these interventions in terms of quality and quantity of ongoing activities and outcomes for the community.

Progress—The first component of this evaluation project has involved an initial assessment of three demonstration sites at the time that ILRU funding through the rural demonstration

grant was discontinued. This initial assessment allowed for the collection of baseline data to be used for comparison purposes following assessments in subsequent years. The second component will be followup interviews of selected individuals living in the demonstration site areas. The third component will involve two followup examinations of these demonstration sites at 18-month and 36-month intervals.

To date, three demonstration sites have been chosen from among those previously established by ILRU. Consultants at each site have conducted the Community Needs and Resource Survey developed by ILRU during its

rural demonstration project, thus establishing baseline data.

Staff will develop the content and format for personal interviews of residents at each demonstration site. This protocol will be pilot tested on a sample of ten individuals at one site, refined appropriately, and administered at all three sites. All data gathered through the Community Needs and Resource Survey and individual interviews will be coded and computer-entered in preparation for comparative analysis after the collection and entry of the data collected at the 18-month interval.

An Operational Definition of Independence

Margaret A. Nosek, Ph.D.

Baylor College of Medicine and ILRU Research and Training Center on Independent Living at TIRR, Houston, TX 77225

Sponsor: *National Institute of Handicapped Research*

Purpose—This project is designed to develop an operational definition of independence that spans four uses of the term: in a behavioral sense, as a psychological trait, in connection with functional abilities, and with respect to individual social performance. The objective is to develop an assessment battery to quantify an individual's independence in each of the above specified domains.

Progress—With appropriate expert consultation, a refined conceptual definition of independence is being generated covering each of the four usage areas. Measurement operations (rating scales, standardized tests, the content analyses of direct observations) will be identified which represent the state of the art in each area. Those measurement operations will be applied to a carefully comprised sample of persons eligible for independent living program services. Multivariate analytic techniques will be applied to the resulting data to identify the factorial structure of those measures, and using the factor analytic results, a practical means will be developed to profile quantitatively an individual's 'independence' and generate a single score or profile of scores that reflects the

individual's independence relative to others. Subsequent projects then will be undertaken to demonstrate utility of this operational definition in evaluating outcomes of independent living programs.

A thorough literature search has been conducted. The results of this search and an analysis of issues surrounding outcome assessment in independent living were prepared for publication as a chapter in *Rehabilitation Outcomes: Analysis and Measurement*, edited by Marcus Fuhrer, to be published in 1987 by Brookes Publishers.

Common characteristics among definitions of independence were extracted from literature dealing with this construct as a psychological trait, a behavior, an indicator of functional abilities, and an indicator of social status. A listing was compiled of psychometric instruments and tools used in independent living program evaluation to assess the level of an individual's independence.

From existing literature and discussions with senior project consultants, a provisional operational definition of independence has been developed. From this, a preliminary assessment battery will be constructed.

E. Communication Methods and Systems for the Severely Disabled

Capuchin Monkeys as Aides for the Severely Disabled

Mary Joan Willard

VA Medical Center, Bronx, NY 10468

Sponsor: *VA Rehabilitation Research and Development Service*

Progress—This project is an ongoing attempt to refine the procedures by which capuchin monkeys are trained to serve as aides for high-level quadriplegics. Progress has been made in meeting the following objectives. 1) Approximately 90 percent of the training procedures used in teaching a basic repertoire of skills have been standardized and described in a 100-page illustrated training manual as well as instructional videotapes. 2) Eight high-level quadriplegics are now using simian aides, with feedback from these placements continuing to allow refinement of our profile of desirable candidates. 3) A breeding colony was established in 1985 at the Mannheimer Primatological Foundation in Florida to produce 20-40 infant Cebus per year. A colony has been located in Argentina, and 16 female infants have been purchased. 4) A non-profit organization has been established, with financial support provided by a corporate sponsor, to apply the knowledge gained from the simian aide research and to place simian aides as mature animals become available, beginning

in late 1987 with 15-20 placements per year. 5) An evaluation of the simian aide research is currently being conducted by the evaluation unit of the Department of Rehabilitation Research and Development. A second unrelated evaluation by the New York University Spinal Cord Injury Research Unit is also planned. 6) Data from a market survey testing the preferences of high-level quadriplegics for simian aides versus robotic arm work tables has been collected. 7) An experimental program for teaching college students how to train monkeys initiated in September of 1985 will be evaluated over the next 2 years for efficiency and cost-effectiveness. 8) Canada, Argentina, and Israel are now beginning their own simian aide programs; training material and primate selection information are being provided to them at no charge. 9) Modifications to the wheelchair mounted laser system, food dispenser, and shock/tone unit are being made to make this equipment more reliable and unobtrusive.

An Optimal, Inexpensive Text Entry System for the Orthopaedically and Neurologically Disabled

Cheryl Goodenough-Trepagnier, Ph.D. and Stephen H. Levine, Ph.D.

New England Medical Center Hospitals, Boston, MA 02111 and Tufts University, Medford, MA 02155

Sponsor *None Listed*

Purpose—The goal of this project is to devise software that makes it possible to customize a text-producing system for an individual who is unable to use the standard keyboard effectively and comfortably, because of neuromotor or orthopaedic disability.

Progress—Our approach makes use of inexpensive, off-the-shelf hardware and the development of software that can allow nonprogrammers to customize a device to a user. Software development falls into two broad areas: field specifiable keyboards, and keyboard optimization.

Two basic techniques may be identified for

field specifiable keyboards: 1) direct input keyboards, for which software is being developed to allow the interfacing of digitizing tablets as specifiable keyboards with a personal computer; and 2) indirect input keyboards, for which software is being developed to display a specifiable keyboard on a personal computer screen and to interface with a number of key selection devices such as joysticks, mice, and trackballs. Each of these techniques utilizes the computer screen to display the text being constructed.

Keyboard optimization approaches under development are: 1) arrangement of keys, for which software has been developed to utilize a user model (user-specific time-dependence on physical parameters of devices), and statistical properties of English to arrange the keyboard items so as to maximize the text entry rate; 2)

coding, for which software is being developed to optimize jointly the coding of characters into several keystrokes and the arrangement of the resultant keys so as to maximize text entry rate; and 3) software has been developed to disambiguate text entered from multiple-character keys; the assignment of characters to keys is optimized with regard to minimizing inherent ambiguity.

A variety of low-cost input interfaces have been evaluated as text production control modes. A pilot assessment of a subject's ability to use a joystick for menu selection has been carried out. Work is in progress to refine this assessment and devise assessments for the other inexpensive control modes. Studies of learnability are planned.

Software Development of Alternate Inputs to IBM PC

Charles Lee, M.S. and Joseph Schauer, B.S.

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, Madison, WI 53705

Sponsor: *National Institute of Handicapped Research*

Purpose—The purpose of this project is to enable individuals with disabilities to access an IBM PC computer using a variety of devices and communication techniques. Current work includes researching scanning techniques that can be used within a window environment, the

development of software, and the completion of the transfer of the LROP (Long Range Optical Pointing) System to a manufacturer for distribution. Each product will be defined and designed, implemented, tested, documented, field tested, and moved to commercial distribution.

PACA—Portable Anticipatory Communication Aid

Craig W. Heckathorne, M.S.E.E.; Dudley S. Childress, Ph.D.; Lew J. Leibowitz, B.S.E.E.; Jerrilyn A. Voda, M.S., C.C.C.S.P.

Rehabilitation Engineering Program, Northwestern University, Chicago, IL 60611

Sponsors: *National Institute of Handicapped Research and Easter Seal Research Foundation*

Purpose—The PACA was a research and development project to design a portable computer communication aid which would enhance the communication abilities of nonvocal persons who also have physical impairments that preclude the use of direct selection techniques. The project had two primary objectives: 1) to augment the utility of traditional scanning communication aids by adding message element anticipation; and 2) to make this scanning communi-

cation aid cost-effective to the user by capitalizing on the benefits of the innovative technology and competitive marketing of an available commercial portable computer.

Progress—The PACA communication aid has been completed. It has been realized as a program, stored in EEPROMs, running on the Epson HX-20 portable computer. The program and Epson have features that support person-

to-person (conversational) communication, note taking, writing, and math calculations. Two operational versions of the program are available: a single-switch automatic scanning version and a two-switch step-scanning version. Neither version requires any hardware modifications to the Epson, other than insertion of the program PROMs. The switch for the single-switch version is connected, through an adapter cable, to the HX-20's bar code reader port. The switches for the two-switch version are connected to a simple low-power electronic circuit plugged into the bar code port.

A significant feature of the PACA program is the use of anticipatory (predictive) algorithms, based on frequency of use, to improve

the efficiency of letter and word selection. Letters and words with greater probability of being selected are arranged in their selection arrays in positions that require fewer scanning steps to select. By ordering letters and words dynamically, in this fashion, it is possible to reduce, on the average, the number of scanning steps and switch activations needed to create a message. The improved efficiency of message creation can result in an improved rate of message generation for persons afflicted with severe motoric involvement.

The PACA program was developed with the support of clinical and field evaluations by persons who are both nonvocal and physically disabled.

CompuTalk

John H. Staehlin, M.S.M.E. and Herb Otto, B.S.E.E.

Westinghouse Defense and Operations Division, c/o VME, Inc., Lutherville, MD 21093

Sponsor: *Volunteers for Medical Engineering, Inc.*

Progress—A talking keyboard has been designed and a prototype of the system has been developed and field tested. It is presently being used at the National Rehabilitation Hospital. The unit is a low-cost assembly making use of available electronic components. In order to operate the unit, one merely types a message and the CompuTalk assembly speaks the words or sentence as soon as the enter key is depressed. The message can be 256 characters long and is read from a liquid crystal display integral with the keyboard assembly. In addition, each of the keys of the standard keyboard can be programmed by the user to have a stored message, 56 characters long, that is nonvolatile and accessed by pressing the function key and then the message bearing key. The plan is now to configure the electronics for producibility. This includes the development of a printed circuit board for automatic interconnections. Additionally, it is planned to incorporate another liquid crystal display so that the person to whom the user is speaking can see what is being typed while facing the user.

Future Plans—The work on the printed circuit

board for the electronics assembly has been submitted to layout for interactive graphics (IAG) creation. When the layout is complete, we will begin the production of the units and assemble a number of prototypes for distribution to the VME Chapters around the country and for use by local institutions dealing with rehabilitation of disabled persons.

We have received a number of constructive comments from client evaluations which we will incorporate into the production version. This will include the second liquid crystal display facing the person to whom the client is trying to communicate and the examination of means for enlarging the keyboard target area for the visually impaired or for those clients who have motor control problems.

Due to the numerous requests we have had for this device, we will be concentrating on making the printed circuit for the electronics packaging and then proceed to manufacture a number of units for distribution to the various chapters and to the rehabilitation facilities for their continual use and evaluation. We will then begin to advertise via the Concepts for Independent Living and other networks to let

people know that it is available. At that time we will have complete documentation and will be well on the way to FDA approval. We will be seeking funding from various sources so that

we can make all of the plans happen in a timely fashion by applying some full-time effort to the project.

Electrically Controlled Talking Tracheostomy Systems

Simon P. Levine, Ph.D.; Daniel J. Koester, B.S.; Ronald L. Kett, M.S.

Rehabilitation Engineering Division, Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center, Ann Arbor, MI 48109

Sponsor: *Rehabilitation Engineering Division, Department of Physical Medicine and Rehabilitation, University of Michigan*

Purpose—An individual can become dependent on mechanical ventilator support because of neuromuscular disease, high level spinal cord injury, or any other condition that seriously reduces respiratory function. For those requiring long-term ventilation, a tracheostomy tube is surgically implanted into the trachea below the larynx. Cuffed tracheostomy tubes are used to protect the inner airways of the lungs and to ensure that adequate ventilation parameters are maintained.

Providing a means of communication to these patients is crucial to their medical as well as psychological well-being. One method of providing verbal expression for a patient using a tracheostomy tube is to partially deflate the cuff, allowing air to flow up across the vocal cords. Another method employs a specially designed talking tracheostomy tube such as the Portex talking tracheostomy tube.

The Portex is a single-cuffed tracheostomy tube with an additional small-gauge air line running along its curved surface and ending just above the cuff. The external end of this air line is connected to a source of compressed air that is regulated to produce audible speech (approximately 5 liters/minute). A "tee" in the air line provides a port to control the airflow to the vocal cords. Air escapes out the control port until the port is covered by a finger, which causes the air to flow through the air line to the vocal cords. It is the quadriplegic patients' inability to close this control port that prevents them from independently actuating a system such as the Portex.

Progress—Several systems for independent actuation of the talking tracheostomy systems have been developed. Different design constraints based on patient needs have resulted in a variety of system configurations. These systems can be categorized into 110-volt AC and 12-volt DC systems.

A 110-volt AC high-pressure solenoid valve can be installed at a compressed-air outlet: either a wall outlet such as those in hospital rooms, or an air tank, or an air compressor. Alternately, a low-pressure 110-volt AC solenoid can be used to open and close the control port on the talking tracheostomy tube, but residual resistance of the valve in the open state causes a small amount of air to flow continuously across the vocal cords, causing dryness and irritation. The air needs to be passed through a humidifier bottle before going to the vocal cords.

A DC relay is used to activate the solenoid valve: DC voltage is obtained from the 110-volt AC line via a simple power supply, which also isolates the patient from the 110-volt AC line current. A momentary, time-latched, or latching switch is used to control the relay and operate the solenoid valve. This system is easily transported with a compressed-air tank cart, but requires a 110-volt AC outlet for operation.

A 12-volt DC high-pressure solenoid valve that is powered by the ventilator battery or a wheelchair battery can also be used. The ventilator and its battery can be mounted on either an electric or manual chair. Pressurized tanks or a battery-operated air compressor are used as the source of compressed air and are also mounted on the chair. A momentary, time-

latched, or latching switch controls the solenoid valve. Occasionally, the ventilator and talking tracheostomy systems do not have a separate battery but use the wheelchair batteries. For that situation an automatic switching relay has been developed to alternate the 12-volt DC drain evenly between two 12-volt wheelchair batteries.

These systems have been extremely successful in allowing patients to independently control their talking tracheostomy systems.

This independent voice control has greatly enhanced communication for these individuals.

Future Plans—Future work will include improvements in mounting systems, air compressors, and all other system components. Options for more automatic control of these talking tracheostomy systems are also being considered. Such a control system is difficult to design as it must sense speech initiation.

A Single Switch Keyboard Emulator for the IBM PC

Lincoln A. Jaros, B.S. and Simon P. Levine, Ph.D.

Rehabilitation Engineering Division, Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center, Ann Arbor, MI 48109

Sponsor: *Rehabilitation Engineering Division, Department of Physical Medicine and Rehabilitation, University of Michigan*

Purpose—The personal computer has become a primary tool for allowing the severely disabled to communicate with and control their environment. In the past, the most commonly used personal computers were from the Apple II family. The IBM PC and PC-compatible computers have become the standard personal computers in business and science, largely because of their superior processing power and memory capacity. Steady decreases in cost have made them an excellent choice for the handicapped user. A special software keyboard emulator called ALTKEY has been developed as an input driver for IBM PC-compatible computers. It is designed to solve the same problem in software that the Adaptive Firmware Card solves in hardware on the Apple II.

Progress—ALTKEY augments the device driver software already present in the basic input/output system read only memory (BIOS ROM) by adding a scanning system that allows each user to design and edit individualized scan menus. Input generated by this system goes to the regular keyboard buffer where it is treated as actual keyboard data.

ALTKEY presents the user with a series of input choices listed across one line of the video screen. These choices are highlighted one at a

time in a repeating pattern. The user makes a specific choice by activating a switch when the desired entry is highlighted. The switch can be one of the shift keys on the keyboard or a momentary switch connected to a game port input. Each selection can display a new set of choices or send key codes to the keyboard or both.

The list of branching menus and entries is called a scan tree. The scan tree is defined in a simple text file called a scan tree definition file. The user can create and edit these files, customizing them for specific application programs. The flexibility of the tree design allows required selections to be minimized by presenting the user with the most likely choices first.

Future Plans—The current version of ALTKEY was designed with the intent to add enhancements on a regular basis. Planned additions include options for two switch scanning schemes and Morse Code entry. There are discussions currently underway throughout the software industry aimed at developing a standard for memory-resident software. When this becomes a reality, ALTKEY will be modified to conform if possible. Until that time, testing with other memory-resident software will continue in an effort to keep ALTKEY current.

Development of a Unified Quantitative Model for Augmentative Communication Systems

Gregg C. Vanderheiden, Ph.D.

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, Madison, WI 53705

Sponsor: *National Institute of Handicapped Research*

Progress—A conceptual model has been designed to assist in the comparative analysis of all current selection-based augmentative communication techniques. Six tests of the model have been completed and documented. Two by G. C. Vanderheiden are in press: "Overview of Selection-Based Augmentative Communication Systems," and "A Unified Quantitative Model-

ing Approach for Selection-Based Augmentative Communication Systems." We also are studying the minimum sample lengths required for stable predictions of user performance, and preparing an additional document: "Testing of Predictive Capability of a Quantitative Model for Augmentative Communication Systems," by Vanderheiden.

Comm-Aid

Robert Leedom, M.S.E.E., M.S.C.S., and Diane Lewis

Westinghouse Defense and Operations Division, c/o VME, Inc., Lutherville, MD 21093

Sponsor: *Volunteers for Medical Engineering, Inc.*

Purpose—The Volunteers for Medical Engineering Inc. (VME) have developed a software program that is intended for the multiply-handicapped persons who have communicative disorders, exhibiting communication developmental levels of approximately 8 months to 5 years. The complete package is actually an authoring system, allowing a therapist/teacher to create a communication device tailored to a specific individual's needs. The program, which runs on an Apple computer, uses a touch tablet (a PowerPad) as an input device. The surface of the pad may be mapped into any arbitrary arrangement of (up to 144) rectangular areas, and each area may be assigned a high-resolution graphic picture and a string of "voice-text." The program then creates a customized disk; start-up with this disk in the drive turns the computer into a communication device. By sequentially pressing areas of an overlay on the PowerPad, the user can produce the corresponding graphic "sentence" on the screen, and hear the voice-synthesized text (via an Echo™ speech synthesizer) at the same time.

Comparing this package to currently available products, Comm-Aid is unique in combining the following features: The customized

touchpad layout allows the therapist to make allowances for an individual's capabilities (in terms of muscular control and cognitive ability). The graphics display may be chosen from a library. By using commercially available software tools, the therapist may modify or add to the library. With speech output provided by the popular Echo synthesizer, vocal feedback can be anything that is meaningful to the intended user. Turnkey operation permits the therapist to appropriately label the disk that the system produces (e.g., "Johnny Jones"). To work with Johnny Jones, the therapist simply turns power on with his disk in the drive.

Progress—All parts of the program are operating: pattern layout editing, graphic selection, and voice-text entry. The automatic package compiler is incomplete; however, a hand-compiled sample disk is being tested with handicapped children to refine the user interface.

Future Plans—First, we will complete the programming of the package as described, and produce the library of graphic symbols under the guidance of a specialist in augmentative communication for the handicapped. Then we

will produce a manual to guide the therapist through the authoring process. Current efforts are proceeding on a "donated spare time" basis

by a member of VME. To permit faster completion and fine-tuning of the project's features, proposals for grant funding are being prepared.

Application of Technology to Enhance the Employability of Severely Communicatively Impaired Individuals

Elizabeth J. Allen, Ph.D. and Andrew Y. J. Szeto, Ph.D.

Assistive Device Assessment Program, Clinical Training Center, San Diego State University, San Diego, CA 92182

Sponsor: U.S. Department of Education—Office of Special Education and Rehabilitation Services

Purpose—One of the major barriers to successful employment for severely disabled clients is lack of adequate communication for the workplace. Although computer technology has been used to augment the communication skills of the nonvocal physically handicapped, little attention has been given to resolving their communication problems related to entering and retaining employment. The purpose of this demonstration project is to develop a multidisciplinary approach for analyzing the communication needs of a client and a particular workplace; for prescribing and customizing an appropriate communication system for that client; and for training that client to have communication competence for the workplace. Removal of the communication barrier to employment is expected to provide greater independence for the disabled with subsequent economic and psychosocial benefits.

Progress—Assessment Phase. A very important feature of this project has been the development of rapid, targeted assessment procedures. Utilizing this approach, it has been possible to identify the type of augmentative communication device needed by a client after two or three two-hour visits to the Clinical Training Center on campus. This not only maximizes use of valuable facilities and staff time, but also reduces the stress of the assessment process for clients whose severe physical disabilities make travel difficult.

Greater efficiency has been made possible due to the comprehensive preassessment evaluation carried out by the multidisciplinary Assistive Device Assessment Program (ADAP) team. The crucial elements of this are: a

screening interview with the referring individual, and a detailed application form and written reports from the potential client's physician and all agencies from which he/she has received service. Based on this information, the team decides whether to accept the client and, if so, what additional information is needed. The ADAP social worker gathers the needed information through additional collateral contacts, one or more visits to the client's home, and, if relevant, visits to the client's school or sheltered workshop.

The application materials and the social work report enable the speech and language pathologists on the team to plan a cognitive/communication assessment that utilizes parts of various standardized tests as well as a variety of informal measures designed for the particular client being assessed. The results from the cognitive assessment are used to guide subsequent evaluations. For example, sections of tests such as the McCarren-Dial and Perceptual Memory Task are used by the vocational counselor to establish the client's probable vocational readiness and direction. Motor assessment procedures similar to the one used by the Sacramento State Assistive Device Center are used selectively by the rehabilitation engineer based on what is already known about the client's physical capabilities. Of course, a complete assessment is done in areas for which there is any question about capability. Following the motor assessment, clients are tested (either directly or through simulation) on several communication devices that might be suitable based on their cognitive and physical abilities.

Vocational Placement Phase. The project team has encountered unexpected difficulty in

securing funding for the recommended augmentative communication devices. To overcome skepticism and to provide stronger documentation, project team members have trained several clients to use the recommended device on a regular basis. Because most of the project clients are too severely disabled to have been eligible for existing vocational rehabilitation programs, project staff members have been working with representatives of various community agencies in developing new routes to the workplace for them. Some of the more promising avenues include placement in sheltered workshops, individualized vocational training programs, and supported work.

Status of Clients. Of the 18 accepted appli-

cants, 14 have been assessed regarding their cognitive and physical abilities for using a communication device. Currently, seven project clients are undergoing some type of training for improving their communication competence and/or vocational potential. Two of the clients have secured their own suitable electronic communication systems, and three clients are in the vocational phase of the project.

Future Plans—During the remainder of this 3-year project, the assessment procedures will be further refined and specified so that they can be duplicated by other teams of professionals working in the areas of augmentative communication and vocational rehabilitation.

Neuromuscular Assessment for Assistive Communication Device

Nathan Rudin, B.S.; L. Donald Gilmore, A.B.E.E.; Serge H. Roy, M.S.P.T.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Purpose—The number of communication and environmental control devices available to severely motor-handicapped individuals has grown enormously in recent years. However, equipping such patients with these devices requires a complex program of neuromuscular assessment, as each person's available motor resources will determine the type of interface used to connect the human and the device. We have embarked upon such an evaluation program with a severely handicapped nonvocal cerebral palsy patient, with the goal of developing a specialized interface for use with an assistive communications device.

Progress—Our investigation has focused on myoelectric activity in the head and neck region (primarily the frontalis and sternocleidomastoid muscles), and on left/right head rotation as device control possibilities. To refine the subject's frontalis control, we have implemented a biofeedback training program using a specially modified myoelectric biofeedback device, the Myobeeper. (This device was described in our 1983 Progress Report.) We will continue our efforts by constructing a prototype interface that will translate head rotation into various voltages suitable for device control purposes.

Investigations on a Communication System for the Severely Handicapped

W. Rossdeutscher, Dipl.-Ing. and U. Boenick, Prof. Dr.-Ing.

Department of Biomedical Engineering, Technical University of West Berlin, D-1000 Berlin 10, West Germany

Sponsor: *None Listed*

Purpose—A particularly severe impairment is the total loss of speech with a simultaneous loss of major motor functions. In such cases at least one residual motor function is an indispensable prerequisite for the maintenance of ability to

communicate with other persons. A communication system based on a personal computer has been developed.

Progress—Only slight modifications are re-

quired to adapt the communication system to different types of, and changing, handicaps. This means that the disabled person is not bound by a rigidly fixed system.

To a particular degree, account can be taken of the individual wishes of the handicapped person with respect to the form of the program, the functions employed, special words, and writing speed. The possibility that the handicapped person will be able to communicate whenever he wishes without being dependent upon any direct aid on the part of others, and with no great restrictions on the form of expression, is the major advantage of this system.

The communication system enables the patient, simply by moving a single finger, to dis-

play any message he wishes on a monitor screen, or to print it out on a printer, and, in addition, to actuate a number of electrical switching functions. The system is operated by the handicapped person via an input device, which can be adapted to the individual concern.

The advantage of this system is the flexibility of the hardware and software. There are costs for additional hardware only as a result of an individual adaptation of the input part.

Future Plans—To complete the project, the following investigations will be carried out: comparison of different types of communication systems and input devices; efficiency of the systems; and optimization of the interaction of system and adapted man-machine-link.

F. Environmental Control Systems for the Severely Disabled

UHCI: Ultrasonic Head Control Interface

David L. Jaffe, M.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—In order to perform some tasks independently, severely disabled individuals must find communication pathways to replace the ones that have been totally lost, or they must amplify those that are impaired. High-level quadriplegics have a particularly difficult time in replacing lost or diminished channels to the outside world, since many of them can control only the muscles at their neck level and above.

Although many interfaces have been developed for use by severely disabled individuals to bridge the gap between body and environment, none has proved to be ideal. Some have sanitation problems (pneumatic puff/sip switches); others intrude physically upon the user (chin-operated joysticks) or are socially objectionable (head wands). In addition, many are limited in their ability to convey the user's will regarding the operation of the device in question.

Recent technological advances have produced eye-tracking and voice-control interfaces, but even these solutions are less than perfect. Eye-tracking interfaces restrict the user's range of vision while communicating. Voice-recognition interfaces have long response times and are limited to a discrete vocabulary, making them unsuitable for real-time control situations involving continuous variables (such as speed and direction).

Successful development of a device that can overcome current interface shortcomings would be of significant value to severely injured individuals who wish to control their mobility, communication, or recreation in a socially acceptable and aesthetically pleasing manner. In particular, the existence of a device that operates at a distance without the necessity of mechanical contact, that uses a control site not required

for normal sensory input, and that is easy to learn and use could be an ideal solution.

An array of ultrasonic distance-ranging sensors can monitor the head position of a severely disabled quadriplegic operator to obtain information for controlling mobility, communications, and robotic devices. Such a device requires no direct physical contact, and is expected to be more socially acceptable and cosmetically pleasing than devices that do.

Progress—An Ultrasonic Head Control Interface (UHCI) that employs two Polaroid ultrasonic distance-ranging sensors to track the user's head position has been developed. As the user tilts his/her head forward and backward, left and right, the UHCI generates control signals as if the user were moving a joystick. These signals can be used to control a wheelchair, a communication aid, a video game, a robotic arm, or any other device that accepts joystick input. Because the sensors require no mechanical contact with the user's head, the user has no reason to feel confined or "wired up" as is often the case with other interfaces.

UHCIs have been installed on two electric wheelchairs. The first, an Everest & Jennings model 3P equipped with a reclining Recaro seat, is in use in France by a quadriplegic woman. The second, an Invacare Rolls IV with a Solo Products Power Pack, is being evaluated at the VA Medical Center in Palo Alto.

Preliminary Results—Both units have been

operational since June 1983. User evaluation has been performed with 10 quadriplegic individuals. After a short demonstration and training session, the subjects were transferred into a chair equipped with the units. Most were able to navigate successfully without problem. They stated that they preferred the ultrasonic head control to the chin-controlled joystick wheelchairs they had used previously.

A generalized interface for a robotics application has also been developed. As with the UHCI, it allows the user to select tasks and control the operation of a mobile robotic arm via head position. In particular, it allows the user to "draw" the desired robot trajectory on a cathode-ray tube.

A technical manual for the UHCI, including background material, electronic schematics, computer program listings, explanations, and illustrations, has been compiled and made available to more than 50 investigators around the world who are considering the UHCI for research or commercialization.

Future Plans—Within the Veterans Administration, a Request for Evaluation was submitted to the Evaluation Unit and approved. Action is under way to obtain funds for the commercial production of four units, which will be evaluated at VA Medical Centers throughout the country. A decision will then be forthcoming regarding the prescription of electric wheelchairs using the UHCI technology for appropriate severely disabled veterans.

Interactive Motion and Graphic Environmental Simulation

Michael R. Zomlefer, Ph.D. and Larry L. Leifer, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The Interactive Motion and Graphic Environmental Simulation (IMAGES) project involves developing simulation technology applications to the specific needs of two diverse populations: those individuals with spinal cord injury and those with visual impairments.

For the spinal cord injury population, or

those with mobility restrictions, the project will provide the necessary tool for safe, cost-effective, systematic research, development, and evaluation of powered wheelchairs. It will attempt to answer such questions as: Who can use powered wheelchairs safely? Under what operating circumstances can they be expected

to perform satisfactorily? What features limit a chair's effectiveness and acceptance? What key features are needed to make these chairs more accessible?

The same tool can also be used to examine the potential uses of robotic aids, the need for mobility of the robotic aid and how this might best be achieved, and the interaction between the user and the aid. Simulation technology could also be used to gain a better understanding of the functional visual capacity of visually impaired individuals, answering such questions as: What does the person with age-related maculopathy, diabetic retinopathy, or glaucoma actually see? How can individuals be taught to better utilize their residual vision? How can a safer, more efficient environment be produced? What are the critical performance specifications for the next generation of diagnostic, training, reading, and mobility aids?

Progress—The IMAGES project centers around a Digital Image Generator (DIG) display, donated

by the Singer Link Company, and three IRIS 2400 graphic workstations. These workstations are located at Stanford (robotic simulations), at the Western Blind Rehabilitation Center (visual impairment simulations), and at the University of Santa Clara (wheelchair simulations). Having three locations of the workstations allows the maximum number of researchers to work on the project while maintaining a common focus around the large DIG display housed at Stanford.

Extensive liaison is maintained with staff at the NASA Ames Research Center because of their extensive experience in the application of simulation technology to aerospace problems. The recently acquired IRIS workstations are in place, and development of appropriate databases has begun. Pilot testing will assess the feasibility of using simulation technology to study wheelchair mobility, the visual needs and abilities of partially sighted travelers, and the application of robotic manipulators to physically disabled users.

Voice-Actuated Control System

Lance Shum, Ph.D.

Westinghouse Defense and Operations Division, c/o VME, Inc., Lutherville, MD 21093

Sponsor: *Volunteers for Medical Engineering, Inc.*

Purpose—The Volunteers for Medical Engineering, Inc. (VME) has designed a low-cost (estimated to be less than \$100) voice control system that will have, in the first prototype, 256 separate control commands. The output can activate a voice synthesizer and a message panel for communication and/or any electrically operated appliance.

Progress—The circuit diagram for the Voice-Actuated Control System (VACS) has been completed, and the parts for the prototype have been ordered. The Sensor Design Group of the VME has been asked to review the design and to suggest design improvements so that the least expensive and most reliable design can be built as the prototype. The current parts list for the control unit shows a cost of less than \$20.

Future Plans—We plan to build several units for evaluating performance. The potential for this low-cost Voice-Actuated Control System is tremendous and will find commercial applicability as well as direct applicability to the disabled person. We will therefore look to the needs of the disabled persons while developing the commercial applicability. The VME plans to form a nonprofit manufacturing division, with this as one of the products that will be sold to create funds for continuing projects.

Information about VACS will be disseminated throughout the VME chapters. It will be listed on the database of the "Tech Net" division of the Concepts for Independent Living Corporation (CIL) and on other hotlines throughout the country in order to provide the greatest possible accessibility.

Design of Showers and Bathing Fixtures for Disabled and Elderly Veterans

Pascal M. Malassigne, M.I.D and James A. Bostrom, M.Arch.
Veterans Administration Medical Center, Decatur, GA 30033

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Moderately and severely disabled people are often prevented from adequate independent bathing in their homes because existing bathing fixtures and other assistive devices do not meet the needs of many of these people. Existing fixtures and adaptive devices are often very expensive, not widely available to the disabled consumer, very specialized in design (for a specific disability, etc.), and not well evaluated for use by disabled people. New bathing fixture designs are needed that meet the varying needs of moderately and severely disabled people of all ages and that are capable of being manufactured in a cost-effective manner.

Progress—Four shower prototypes have been developed using participatory design methods and structured evaluations of the use of each fixture by disabled subjects. The design and development process uses full-size prototypes made of fiberglass that are modified and then evaluated using an evaluation protocol consisting of pretrial and posttrial interviews, photographic and video documentation of subject trials, and documentation of user comments and suggestions. Disabled subjects are recruited from the Atlanta VA Medical Center and from other Atlanta centers providing rehabilitation, independent living services, and support for disabled people.

Preliminary Results—Four shower prototypes were developed initially and then evaluated during 1984 and 1985. They included: 1) a cushioned shower designed primarily for people who are capable of transferring to and from a wheelchair with little or no assistance; 2) a fiberglass shower with two integral seats designed primarily as a test prototype for evaluation of the bathing abilities of right and left hemiplegics; 3) a roll-in shower with seat designed for people who can transfer; and 4) a two-piece roll-in shower designed for people who shower

in their wheelchair, which permits independent use when possible and accommodates assistance by an attendant.

Based on the results of the evaluations, the basic design of three of the showers (1, 3, and 4) was found to be appropriate. Minor modifications to improve usability of the prototypes and to develop the designs for future manufacture are now being completed.

The two-piece roll-in shower has been modified to increase the depth of the unit, improve the design of the floor, and develop a shower curtain system capable of being operated manually or with a power operator. The new version of the roll-in shower is now being evaluated at the Atlanta VA Medical Center. The seat and the grab bars provided with the roll-in shower have been modified and this new design also is being evaluated by the investigators. Another seat is currently under development that will feature a cushioned surface and a specially contoured seat area. This design will be based on the design of the fiberglass seat but will require some detail changes due to the use of the cushioning material.

The design of the cushion shower is being modified to correct a problem with the fixture size and with the positioning of users in the fixture during bathing. The current design of this fixture provides very good lateral trunk support and body stability. This is accomplished by the use of a contoured seat and back area combined with a raised floor under the user's feet that acts to push the user back into the seat.

Unfortunately, many subjects experienced pain and discomfort caused by the raised floor and by inadequate space in the seat and back areas. The current design does not accommodate users who are moderately overweight although this type of fixture would be very useful for this type of user. Modifications to the current design are planned that will continue to provide good body support while increasing the

dimensions of the seat area and lowering the floor height.

Future Plans—Modifications to the two-piece roll-in shower and to the roll-in shower with seat (both fiberglass and cushioned versions) are being completed. The cushioned shower that is being redesigned will be fabricated and then evaluated. A new shower seat is being developed and will be evaluated for use in exist-

ing bathtubs. This design will use the seat design from the roll-in shower with seat and will add a tubular frame designed for use in a bathtub. Following the completion of the fixture modifications and the evaluation of the improved fixtures, the investigators will complete the work on an illustrated applications workbook that explains how to select the correct fixture based on user need, how to install that fixture, and how to use the fixture safely.

Development of a Robotic Arm for Use by the Physically Disabled

Gary Birch; William Cameron; Johnathan Young, B.A.S.C.
The Neil Squire Foundation, Vancouver, B.C. V5Z 4C9 Canada

Sponsor: *TRIUMF, National Research Council of Canada and Health and Welfare Canada*

Purpose—The objective is to develop a reliable robotic appliance that will provide severely physically disabled persons with the capability of manipulating selected items in their environment in such a manner that these users will continue to use the appliance on an everyday basis. Based on an extensive survey of previous work in this area, interviews with potential users who are severely disabled, occupational and physical therapists, and service delivery specialists, a design criteria and "wish list" of reasonable tasks were established. The final product price will be comparable to that of an electric wheelchair.

Progress—Development work on a robotic manipulator to meet these specifications has been carried out by the authors during the past 3 years. The manipulator geometry, which is human size in scope, was initially designed to perform tasks in the workstation environment. The arm geometry is horizontal axis-cylindrical coordinate and consists of 3-degrees-of-freedom for object positioning and 3 degrees for orientation plus 1 degree for gripper actuation. The versatility of the arm is enhanced by an end effector exchange, which will provide special-purpose grippers for program tasks. The manipulator is lightweight and portable. All degrees of freedom may operate simultaneously under digital P.I.D. control. The working envelope is defined using software boundary limits.

Any computer with an RS-232 serial port, typically an Apple or IBM PC, can be used for supervisory control. It is through this computer, using various input techniques such as Morse code keyboard emulators, keyboard scanning systems, or voice input systems, that the disabled user will be able to control the arm.

As much as possible, the tasks are carried out under program control to minimize the need for user input. However, the user has the ability to interrupt these programmed tasks to make spatial adjustments if required. The programming of a task is based on a lead-through-teach concept that is performed by a friend/attendant, or by a set of manual move commands that will allow the user to single-step through a desired routine. At present, the manipulator is capable of performing such tasks as picking up a manual from a bookshelf and placing it in front of the user; turning pages; picking up, serving (with a straw), and replacing a drink; serving a mouthstick; loading a diskette; picking up an electric razor and shaving a person; brushing hair; and brushing teeth using an electric toothbrush.

Future Plans—The Neil Squire Foundation currently has two third-generation prototype robotic arms. The future development of these arms will be based on field testing in hospital and group home situations conducted in the fall of 1986. Safety precautions will continue to be a

high priority. One of the safety features that will be included is hardware redundancy employing a separate CPU and power supply to monitor the operation of both the low-level and supervisory controllers. In addition, a direct user panic stop system will be implemented in hardware. Software precautions will include a self-test on system start-up, monitoring control-

ler error and output signals for appropriate behavior, and reducing critical trajectory torque in zones that could possibly result in injury. Gripper development and refinement will also be an ongoing concern. A later version of the manipulator will be a bedside unit mounted so that the arm will swing over the bed to face the user when called into service.

Investigation of the Utilization of a Robotic Arm by Disabled Persons in the Workplace

Leonard L. Anderson, M.S.E.M.

Cerebral Palsy Research Foundation of Kansas, Inc., Wichita, KS 67208

Sponsor: *Wichita Rehabilitation Engineering Center*

Purpose—Persons who have disabilities that limit arm and hand functions cannot perform manipulative tasks that are often required on the job. In recent years, robots of various designs have been developed for use in industry. The researchers of this project felt that the robotic arm has potential as a manipulative tool that would allow physically disabled individuals to perform workstation tasks currently beyond their capability.

The objectives are to investigate the feasibility of the utilization of industrial robots, specifically robotic arms, to complement the existing available motions of a disabled worker, and to validate their effectiveness using disabled workers performing industrial tasks.

Progress—The originally proposed methodology called for the purchase of two robotic arm devices and assigning them to workers at two different workstations at Center Industries Corporation (CIC) in Wichita. Subsequently, a third workstation was developed at CIC in which a robotic device would be designed and installed on a machine that would provide for continual adjustment previously performed manually by the machine operator. These adjustments were the only barrier that prevented a severely disabled worker from operating the machine. A suitable device has been designed, fabricated, and installed on this machine and is currently in use.

Two small robotic arms, complete with mi-

croprocessors, and manufactured and marketed by Microbot, Inc., were purchased. They are of the type that maintains a base position but have all of the motions that the human arm is capable of performing. To the "hand" of the device must be added an end effector or gripper to facilitate the handling of parts or materials.

One workstation at CIC in the Boeing tinning room was selected to utilize one of the robots. A worker who is quadriplegic from cerebral palsy has operated this workstation with success, maintaining production and quality standards.

The robot grasps, one at a time, small electrical resistors having wire leads from a holding fixture. It then dips the wire leads into a liquid flux, then in molten solder, and deposits the part in an alcohol bath. The worker ensures that the next part to be manipulated is in the holding fixture by the time the robot is ready to grasp it during the normal cycle. The worker observes the operation to ensure quality and uses a special tool for periodically skimming dross from the surface of the molten solder. The proper depth of solder is maintained by the worker dropping small beads of solder into the pot. Using the teach pendant, the programmer manually operates the robot through the positions required in the cycle of operation. The microprocessor remembers the steps and repeats the cycle automatically when asked by the operator to do so (i.e., pressing "RUN" button on the teach pendant).

The robot, after grasping the part, moves to immerse its wire lead in the liquid flux and then to the molten solder that is contained in an electrically heated pot. The part is then turned end-for-end and the dripping process is repeated before depositing the finished part in the alcohol bath.

A third robotic arm, called the Armatrol, marketed by Feedback, Inc., was investigated. The Armatrol offers all the operating functions of the Microbot unit except for "roll" of the "wrist." The significant difference between the Microbot unit and the one by Feedback is that the Feedback unit operates with servomotors, whereas the Microbot unit operates with stepper motors. Programming of the Feedback unit is accomplished by a computer keyboard and is more difficult to understand by persons who are not knowledgeable of robotic language. It is felt, however, that servomotor technology provides for more dependable positioning of the "hand" because the position feedback system is located on the output shafts of the drive motors.

Staff members were able to set up the Armatrol in the tinning workstation. The type of electrical components handled was limited due to the inability of the "wrist" to rotate. The unit operated quite satisfactorily until contract requirements for that particular component diminished. Efforts are under way to find another suitable task for this device.

More recently, an industrially rated robotic arm was purchased. This is the Alpha, manufactured by Microbot, Inc. The manipulations of the arm are the same as the models purchased earlier in the project. Drive motors and the electronic controls are of a quality to ensure dependable operation on a continuous basis in a

rigorous production environment. Project staff are currently learning its sophisticated capabilities and programming procedures. It is anticipated that a workstation will be chosen in the near future for operation of this robotic arm.

Preliminary Results—Results of the operation of the first two workstations by a robotic arm to assist a severely disabled worker have shown the concept to be a viable one. During the time of consistent behavior by the robots, production rates and quality were comparable to those of manual operation by able-bodied workers. Additional workstations are being sought for robot implementation at CIC.

Members of the staff continue to be extremely encouraged at the prospect of the use of small robotic arms to provide the manipulative tasks required at workstations that physically disabled persons could not otherwise accomplish. Costs of new devices are being continuously monitored. If a reliable, low-cost, robotic arm can be found, it is obvious that it can provide a cost-effective means for severely disabled workers to work at a pace that is both quantitatively and qualitatively productive.

One major conclusion can now be made. It is not currently feasible to assume that anyone, disabled or nondisabled, can be expected to perform manufacturing operations that are not highly repetitive in nature. The operation of a robotic arm in a manually controlled mode is not fast enough to satisfy production requirements performed by an able-bodied arm or hand for jobs that require random movement and choices. Robots work best when activity is repetitive and accomplished in the same sphere of operation.

Machine Vision

Michael O'Riain, Ph.D.

Royal Ottawa Regional Rehabilitation Centre, Ottawa, Ontario K1H 8M2 Canada

Sponsor: *Royal Ottawa Hospital*

Purpose—The objective of this project is to design a machine vision system for use with our microprocessor-controlled electric feeder

and with other manipulative aids for handicapped persons. Aids for handicapped persons that involve manipulation (e.g., electric feeders)

are almost universally open-loop systems, which give rise to many problems, including: wasted motions, nonoptimum trajectories, and even injury to the user. The advantage of having a machine vision system that can "see" its environment and act upon what it sees is obvious. The main reasons why such systems do not already exist include the current developmental state of the technology and the high cost of machine vision systems in terms of hardware, software, amount of memory required, analysis time, etc.

Progress—In the machine vision system we

have chosen, 32 light emitting diodes (LEDs) are placed in a semicircular path, facing the object to be scanned. The LEDs are turned on, one at a time in sequence, producing 32 sequential beams that are deflected by the object. The reflected beams pass through a set of lenses and finally reach a lateral effect photodiode (LEP). Currents produced by the LEP give the coordinates of the reflected beam, which are then fed to the microcomputer for shape analysis. Work on this project is continuing in association with Dr. David Gibbons of the Department of Electrical Engineering at the University of Ottawa.

Blinkwriter

Robert Murphy, M.A. and James Brackett

Westinghouse Defense Center, Baltimore, MD 21203 and Volunteers for Medical Engineering, Inc., Lutherville, MD 21093

Sponsor: *Volunteers for Medical Engineering, Inc.*

Progress—A system for the operation of a computer using the blink of an eye has been developed by the Volunteers for Medical Engineering, Inc. (VME) and is currently being evaluated by a number of clients in the Baltimore and Washington area. The unit operates by emitting an infrared signal that reflects off the eyeball and is then detected by a detector adjacent to the infrared source. Both of the components are mounted in an assembly that attaches to the frame of one's glasses in between the lens and the eyeball. The circuitry and software are designed so that the connector from the source and the detector connect to the same port of the Commodore C-64 computer and control a moving cursor on the computer monitor.

The cursor moves down the screen at one of a number of predetermined rates and when a deliberate eyeblink is detected the cursor stops stepping down and separates at the first item on the line. It then steps across the screen until the second eyeblink occurs, whereupon the item is printed at the base of the screen. Messages can be written, typed, and spoken if desired.

An adaptation of the system also allows one to control household appliances and the like with the blink of an eye. The next phase of this development is the modification of the cir-

cuitry to make it less sensitive to changes in the ambient light conditions. Breadboard circuits have demonstrated that the new concept using modulated infrared is quite effective. Simultaneously, we are developing the cartridge version of the software so that a user can accomplish the communication using only the C-64 computer and monitor.

The original design of the Blinkwriter is established and is being used by clients for evaluation. The new version with the modulated signal is under development and a breadboard model of the concept is being tested. This is proceeding slowly due to the limited free time of the volunteer. With a concerted effort the design could be ready for client evaluation within 3 months of project approval.

We are also simultaneously working on the enhancement of the software package and the potential transfer of the data to a cartridge so that it can be used without a disk drive. The attachment of the device will now be possible on the outside of the glass frame with some additional design freedom. A new low-cost clamp-on mechanism has been configured and is presently being laid out for manufacture.

Future Plans—The design for the modulated

infrared source circuitry and its adaptation to the eyeglass frame will be completely designed and detailed in its final configuration so that it can be manufactured. This will entail considerable drafting and engineering effort.

Effort up to this time has been voluntary, thus the project has proceeded at a very slow

pace. We are getting many requests for this product and would prefer to deliver the enhanced model to the clients so that they can best apply the device for their communication with others. We are therefore seeking funding for some of the design to allow timely completion of the tasks.

VME—CAD

Wilson Rivera, BSCS; Michael Maher, BSEE; John Staehlin, MSME
Volunteers for Medical Engineering, Inc., Lutherville, MD 21093

Sponsor: *Volunteers for Medical Engineering, Inc.*

Purpose—The Volunteers for Medical Engineering, Inc. (VME) has started a program for teaching disabled persons how to use the computer and the computer software for Computer-Aided Design (CAD), and to show them how they can use this for gainful employment. One muscular dystrophy client is presently using the Robo-Graphics™CAD system and only needed initial encouragement and training to become gainfully employed, competing fully with others in the field. For another client this same CAD system has been modified for full operation using the mouth and head motion. A proposal has been submitted to Anne Arundel County (Maryland) Office of Manpower for VME to set up a pilot CAD training center for disabled persons in local community colleges so they can participate in the technology employment market of Baltimore/Washington.

Progress—One person has been given the computer setup and the CAD package and has been trained in the use and application of the technology. He was offered a job based upon work he performed for a customer on a subcontract basis. Two Baltimore area community colleges have tentatively agreed to allow use of their facilities for teaching CAD to disabled persons.

The adaptation of the controller for the

Robo-Graphic CAD system for use by a quadriplegic has been completed in a prototype form and is now being tested for adequacy. The client will soon be asked to evaluate this system. We will supply the computer and the CAD package to him for this evaluation.

The VME has received a donation of the AutoCad™ software and is currently evaluating it. VME is also looking at means for using Microphonics™ voice inputs to the system and considering the use of the Personics head control system in conjunction with the software.

Future Plans—In addition to the proposal already submitted, the VME plans to generate other similar proposals to allow the expansion of the training program. We will be recommending to our other chapters in the Westinghouse R&D Center in Pittsburgh, Pennsylvania, at TRW in Redondo Beach, California, and at LTV in Dallas/Ft. Worth, Texas that they set up similar training programs.

Work will continue on the evaluation of the voice input operation of the CAD software and on the development of its adaptation for the individual client needs. We will be seeking funding for the timely completion of some of these adaptations and for support of the training programs being set up.

Voice Control for Disabled Children

Barry R. Seeger, Ph.D.; David F. Radcliffe, Ph.D.; William Holmes, B.E.

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, P.O. Box 209, Kilkenny, S.A. 5009 Australia

Sponsor *Apple Education Foundation*

Purpose—Voice input is an emerging technology that will allow a vocal but physically limited person to operate a computer. A recent survey at this center indicated that there is a small but significant need for voice-recognition communication systems. The objectives of this project are to 1) develop software to enable disabled school children to use voice input instead of a keyboard to access the Apple IIe computer; and 2) develop software to enable pathologists to train improved articulatory discrimination in speech-impaired children.

Progress—A successful application for an Apple Education Foundation Grant led to the supply of an Apple IIe computer. This computer has assisted in the development and use of software for this project. To accomplish the first objective, initial equipment testing and software modification were carried out during the first 6 months of 1985. An initial test group of five children then worked with the equipment, which allowed refinement of the software and procedures.

Information gathered during this time was collated in a paper, "Devices for Expressive Communication," presented at the Technical Aid for the Disabled Seminar and published in the seminar proceedings. It shows how the software supplied with the voice input module has been modified and used by children at Regency Park. Initial conclusions are drawn about the effectiveness of voice input for the disabled.

Based on these initial conclusions, an as-

essment scheme aimed at introducing children to the equipment was conducted during 1985 and 1986. The programs developed during this work have been combined with documentation to form a software package available for sale.

To accomplish the second objective, we utilized a case study published in the October 1985 issue of *Archives of Physical and Medical Rehabilitation* by researchers in Canada illustrating a procedure for using computer speech recognition to improve articulatory discrimination. Software employing the technique has been developed for use with the Apple VIM and is being assessed by members of the Speech Therapy Department.

The software allows the therapist to store examples of the client's speech, which are then compared with the client's subsequent attempts. Images are displayed to reward the client for correct attempts. It is expected that this will motivate the children to improve articulation. The software allows the therapist to quickly and easily modify several options as required. It is expected that minor software refinements will be made in response to the speech therapist's recommendations. Documentation is being prepared to form a software package that will be available for purchase.

The overall project was completed in December 1986. We expect that a package will then be available containing software and documentation. A master's thesis is available that provides background information to therapists working with disabled people on voice input.

Overhead Rail Adaptation

John Staehlin, M.S.M.E.

Volunteers for Medical Engineering, Inc., Lutherville, MD 21093

Sponsor: *Volunteers for Medical Engineering, Inc.*

Purpose—The Volunteers for Medical Engineering, Inc. (VME) has developed and is manu-

facturing an aluminum cast wall bracket that, when properly installed on opposite walls of a

typical-sized bedroom, allows the disabled person who has difficulty getting from the bed to a wheelchair to have an I-beam installed between the walls. With the I-beam installed, a number of hoists and trolleys available from standard supply catalogs can be mounted from it and used for lifting and transporting the disabled person.

Progress—The VME has installed two such units for clients. The author has personally supervised the installation and has been lifted and transported by each setup. In each instance, clients have chosen a hoist and trolley that have ratings for 500 pounds and 1,000 pounds respectively, selected from a local equipment suppliers' catalog.

The electrical outlet used for the electric hoist is the standard ground fault isolator type. Additional safety cables have been incorporated from the trolley over the rail and from the body of the hoist to the trolley to provide double the normal capabilities of the rated equipment load capacity. The wall brackets and the I-beam have been sized to support a 300-pound person when installed properly in a typical 12-foot-wide room.

The overhead rail setup is designed strictly

for client transfer. No provisions are made for this setup to be used for bathing. However, a commercially available lift mechanism that the client could purchase is specifically designed for use in bathing and whirlpool applications.

Future Plans—A complete structural analysis will be performed to cover the beam and brackets to see how large the safety margin is on this setup and to have formal documentation. We will be seeking funding to have an independent engineering consultant firm do this formal analysis for added verification of the adequacy of the design.

The analysis and the bracket specifications will be made available to other chapters of the VME at the Westinghouse Research and Development Center, Pittsburgh, Pennsylvania; at TRW in Redondo Beach, California; and at LTV in the Dallas/Fort Worth, Texas, area so that clients in these locales can have this overhead rail adaptation available to them. We will also have this product available on the Tech Net database of the Concepts for Independent Living.

VME has been searching for liability insurance coverage and is taking every step available to them for obtaining it. Information that will help solve this problem is requested.

Development and Evaluation of an Advanced Manipulation Aid for the Severely Disabled

Larry Leifer, Ph.D.; Inder Perkash, M.D.; Robert Chase, M.D.; Stefan Michalowski, Ph.D.
Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The psychological and economic importance of independently accessing and controlling one's own surroundings has long been recognized by disabled individuals and rehabilitation professionals. This need has only been partially addressed by human attendants, trained animals, and special-purpose devices such as environmental controllers. Robotics technology offers a relatively new partial solution. The true value of user-programmable robots lies in their being general-purpose manipulation tools. Generality is required to ma-

nipulate household objects when circumstances change unpredictably.

It is estimated that the cost per year (44 percent direct costs; 56 percent indirect costs) for all new head and spinal cord injury cases in the United States is \$2.4 billion. In 1983, there were more than 3,000 cases of quadriplegia treated in the Veterans Administration alone.

In addition to the economic aspects of disability and rehabilitation, there is the incentive to provide physically limited people with increased independence, privacy, and control over

their personal space. The replacement of lost motor skills, through sensitive application of robotic technology, has the potential to enhance the quality of life for a great many people.

The feasibility of our approach to robotic aids has been demonstrated through the development of a first-generation user-programmable robotic aid. Clinical evaluation of this system has helped us identify key areas requiring further research and development. With these factors in mind, we are now working to move robotics from feasibility to utility.

It is hypothesized that a practical robotic aid can be developed to enhance the independence of a disabled user by successfully addressing the following technical problems: 1) a means of communication management to facilitate human-machine interactions by sustaining an effective "conversation" between the user and the computer; 2) sensor-driven reflex control loops to reduce the operator's workload and ensure rapid system response to grasp and obstacle-avoidance problems; 3) intelligent path and motion planning to reduce the system's dependence on a structured environment, and to reduce the operator's work load; 4) a vehicle to extend the robotic aid's working volume beyond the fixed tabletop environment; and 5) instrumentation and a formal strategy for testing to measure utility objectively.

Progress—A powerful computing environment has been created to do software development in the areas of human-machine interaction, real-time control with sensory input and multi-axis output, and application programming. Concomi-

tantly, devices and equipment needed to realize these goals and instrumentation needed for debugging and refinement have been developed over the past 2 years.

A unique, three-wheeled, omnidirectional mobile base has been developed as part of the Robotic Aid Project. The use of this vehicle extends the working volume of the robot from floor to shoulder height and includes most interior spaces, except for those requiring the use of stairways.

The system has been designed to perform vocational, recreational, and daily living tasks such as food preparation, food service, and personal hygiene. To accomplish these tasks, the following features are among those being developed and refined: 1) an instrumented bumper system for obstacle detection and avoidance; 2) a gripper with optical range sensors for grasping and surface detection; 3) a force-wrist to measure contact forces between the hand and the world; 4) a television camera and wireless radio link for remote supervision and sentry duty; 5) a high-speed radio link to allow the mobile unit's computer and the user's command station to exchange information; 6) an ultrasonic head position detector to act as a two-axis joystick for screen cursor, arm position, and mobile base path control; 7) a high quality graphics monitor to display a map of the remote robot's working environment and manipulation activity; 8) an ultrasonic ranging system for the base to detect nearby obstacles before contact is made; and 9) a laser scanning system on the base to accurately determine its location.

Design of a Six-Axis Joystick for a Robotic Manipulation Aid

Machiel van der Loos, Engr.D. and Larry J. Leifer, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The Robotic Aid Project is developing a prototype mobile manipulation system that incorporates a number of human interface modes. Piloting the mechanical arm and the mobile base in real-time is expected to be accomplished more successfully through a joy-

stick-like device that directly uses the motor capabilities of the individual, rather than by keyboards or voice alone. The problem is that currently available joysticks do not offer the flexibility of accessing many different motion degrees-of-freedom.

Our "VIDOF," a six-axis control interface, seeks to overcome that problem. It was hypothesized that a design allowing control of all six-degrees-of-freedom of the robot could be achieved by a joystick interface device. Pointing the joystick in a certain way and involving all joints simultaneously would imply robot movement in that direction. Such a joystick, in combination with a high-level command capability such as a voice command, would enhance the performance of the manipulation aid now under development.

Progress—The first phase of the design work involved the implementation of a six-axis joystick prototype for able-bodied users. That stage verified the "pointing" hypothesis. Subsequent evaluation by invited disabled testers provided information for the redesign of the joystick and for the modification of the human-interface software, which combined the joystick control with the voice input mode.

Three prototype versions of VIDOF were

built. The third of these was implemented on the first-generation Robotic Aid in 1984.

Preliminary Results—Qualitative feedback from approximately 20 users, including several individuals with quadriplegia, revealed that using the device requires a certain amount of training for the operator to attain confidence in making complex, high-speed maneuvers. Individuals with minimal arm motion had difficulty in manipulating the smaller VIDOF controls. All users mentioned the need for more sophisticated software to render the joystick more adaptable to individual preference and ability.

The development and evaluation work on the current prototype of VIDOF is complete. Future plans for the prototype include incorporating the unit into the Advanced Robotic Aid, so that a more integrated software effort can proceed. A flexible implementation will be important to permit testing of other joystick-type devices.

Design of an Omnidirectional Mobile Robot as a Manipulation Aid for the Severely Disabled

Machiel van der Loos, Engr.D. and Stefan Michalowski, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—A robot intended for human service applications, such as the Mobile Advanced Robotic Manipulation Aid, has very different design constraints than either an industrial robot or a classic telemanipulator system. For one thing, it must be able to perform certain operations autonomously and yet be continually responsive to human intervention to redirect the progress of its task. For another, it must incorporate those features that will make it compatible with the many complicated "real-life" environments of home, clinic, and ward. In the process of proving that robotics technology is appropriate and feasible, it became clear that mobility would be a key requirement for a truly useful rehabilitative device.

Progress—The search for an appropriate

mobile robot base culminated in the development of a vehicle that employed the "Metamotion" principle invented by William La. The vehicle is propelled by three motorized wheels that have tangential rollers around their circumferences. Each wheel can roll in the direction perpendicular to its axis and slip in the direction parallel to its axis, allowing the vehicle to move in any direction. The result is a vehicle that is compact, utilitarian, and omnidirectional. Because it can move sideways as well as forward and backward, and can turn in place, this vehicle is well suited for maneuvering in tight quarters.

Currently, the base with its PUMA-260 arm is operational. Controlled by its LSI-11/73 controller, the vehicle is capable of speeds of 1.5 miles per hour and can negotiate 12-degree

slopes. Battery power (± 36 volts, at 34 ampere-hours) is sufficient for 3 to 6 hours of operation. The electronics bay holds the main CPU, controller backplanes, motor power amplifiers, switch panel, and the radio link to the base station. Externally, there is an instrumented bumper system to notify the controller of collisions, which can be useful both for safety purposes and on the occasions of intentional contact such as when pushing chairs.

Future Plans—Future work centers on the construction of at least two more bases, one with an arm and one for mobility and navigation research. These two bases are expected to benefit from more recent technology than the first prototype. Plans call for high-efficiency power amplifiers, an improved chassis design, more robust drivetrain components, and a more versatile battery configuration.

Computer Configuration of the Advanced Robotic Aid

Stefan J. Michalowski, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The Robotic Aid Project initially combined a standard robot arm with a small computer to coordinate the human interface features central to a human service robot system. While we did prove that the technology was feasible, we also learned that much more computing power was required to deliver a useful manipulation device that incorporated a variety of sensor and motor systems. A suitable and powerful hardware and software environment had to be found to launch the programming effort of the advanced version of the system.

The major components of the first Robotic Aid are a PUMA 260 robotic arm, a two-fingered gripper, a Z-80-based supervisory computer, a speech-recognition unit, a speech-output device, and a status display. A user can "pilot" the arm in real time using spoken commands. Locations can be assigned names, and the arm can be returned to any one of them at a later time with a single command.

The programming was done primarily in Z-80 assembler and PLZ. For the main control program, the typical edit/compile/link cycle for a module was 30 minutes, with a total of about 30K bytes of machine code produced. It is clear that the microprocessor severely limited the development of the software.

To build a powerful tool for program development, we postulated that unified hardware and software environments were essential. In

addition, the larger the computing facility, the more dramatic would be the effect on productivity, since all the researchers could work in concert on the various elements. Finally, the more integrated the programming language, the less significant the compatibility issue would become as the project became larger.

Progress—We have unified the computing system by adopting the 22-bit Q-bus standard of Digital Equipment Corporation. It supports the LSI-11 line of 16-bit processors, as well as the single-board KXT-11 and the 32-bit MicroVAX. A wide variety of peripheral equipment is available for this bus standard, especially for real-time applications.

The second reason we chose the Q-bus was to take advantage of a high-level real-time programming language—MicroPower PASCAL. This language is powerful for handling situations that require concurrently run processes. Through a system that makes use of semaphores, inter-process communication data packets, and priority tables, the processes gain temporary control over the CPU in an organized way. A powerful debugging facility allows the examination of variables and the setting of breakpoints. The VMS operating system allows several programmers and engineers to edit, compile, link, download, and debug their applications simultaneously.

Preliminary Results—The hardware of the mobile robot is an LSI-11/73 with 256K of RAM, four serial ports, and three parallel ports: one serving the three base-controllers, one serving the six arm controllers, and one for miscellaneous input/output (I/O) functions. A KXT-11 supervises the hand and its 12 sensors. The serial ports handle data transmission with 1) the command workstation through a radio link; 2) the on-board status display; and 3) the VAX for program downloading and debugging.

The software at present runs the wheels and arm joints simultaneously from commands sent over the radio link. Specifically, the concurrently running modules are the "Commander" to handle data I/O with the radio link and the status display processes; the "Clock" to

handle interrupts from an external 140Hz source and activate appropriate cyclic processes such as "Mover"; "Radio" and "Keyboard" to handle the protocol for data and command passing for the wireless link and the on-board terminal; "Trouble" to handle error conditions; "Mover" (the central computing process) to implement the kinematic calculations for coordinated hand/base movements; and "Joints" to send the Mover's output to the arm and wheel controllers.

Future Plans—Projected enhancements to the software include servicing the input signals from the sensor systems currently being developed on the test bench, and integrating the hand-control algorithms to the main program.

Force/Proximity Integrated Sensory Perception for the Robotic Aid System

Hisup Park, M.S.; Ho Seong Lee, M.S.; Stefan Michalowski, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—A robotic aid for severely handicapped people must possess the ability to adapt to a changing environment and to interact with its user. This requires an effective sensory system for the robot.

Progress—The VA/Stanford University Robotic Aid Project (RAP) is currently developing a combined sensory system consisting of a tactile force-wrist and an optical proximity-sensor for the robotic manipulation aid. Proper integration of two independent sensory systems has many potential benefits. The fundamental improvement over a single-sensor system is that a much wider range of information becomes available, allowing the robot to negotiate much greater variations in its environment. Beyond this, the integration of multiple sensors can alleviate or remove the limitations and drawbacks of individual sensors, thus providing a more effective and reliable sensory system. The individual sensors will even be able to "cross-examine" each other where their sensory data overlap, as an aid to ensuring proper operation and calibration.

Both the force-wrist and the optical proximity sensors have been a part of RAP's past studies of robotic sensation. Recent progression in our research has revised the role of the sensors, conceptually, from being independent units to becoming components of an integrated sensory system. The corresponding upgrading of the hardware environment for these sensors to a multiprocessor system, consisting of a DEC LSI-11/73 and two KXT11-CA peripheral processors, made the sensory integration possible.

The force-wrist consists of eight sets of strain-gauges mounted on the stressed beams of the robot's Maltese-cross wrist. A transformation routine converts the signals into six force/torque components. The proximity sensors consist of 16 infrared emitter-receiver pairs mounted on the fingers of the robot's end effector. Each sensor is interfaced to a separate KXT11-CA dedicated peripheral processor. These processors run in parallel with the LSI-11/73 central processor. The resulting parallel processing of the sensory data prevents overloading of the central computer.

An aspect of this sensory system not found

in systems for industrial robotic applications is the emphasis on close human interaction. A provision for active human intervention in the supervisory control tasks of the intelligent controller is intended to give the user the power to customize the manipulation tasks when desired. In addition, the integrated sensation, in conjunction with a set of reflex motions, will make the robotic aid system much more suitable for operation in close proximity to a human user.

Preliminary Results—Currently, both the force and proximity sensors are operating; hardware interfacing among the sensors and the computer components is nearly completed; the software interface for the communication between the LSI-11/73 and the KXTs has been written; and software development and algorithm test-

ing for the force/proximity ISP is underway.

All routines were written in DEC's Micro-Power PASCAL concurrent programming language. Various control algorithms have been organized into a set of processes that vie with one another for the CPU time. The priorities of these processes, in conjunction with a coordination mechanism called semaphores, were used to define the hierarchical control structure of the robot.

Future Plans—Ultimately, the force/proximity integrated sensory perception (ISP) system is intended to add the following features to the existing Robotic Aid system: 1) reflex motion; 2) obstacle avoidance and object detection; 3) surface/force contour following; and 4) sensory data reinforcement and verification.

Architecture of the User-Interface Software of the Robot Control Workstation_____

Laurence Edwards, M.S. and Stefan Michalowski, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Writing the programs for the user interface to the robot requires an orchestration of all the various peripheral devices involved in the communication of information to and from the user. Since it is necessary to experiment with the configuration of these elements, a major problem to address is the flexibility and modularity of the software components of the interface.

A second problem, perhaps even more crucial, is the design of the display of information to the user through the use of synthesized voice, color cues on the screen, and other modes appropriate to the information being presented. In addition to the "performance" of the data I/O, one must keep in mind that the system is being designed for a personal computer, not a mainframe.

The first generation of the Robotic Aid was difficult to use because its human interface was slow and limited. The second system will seek to demonstrate the utility of robotic technology in rehabilitation; for that, the human interface will need to be significantly enhanced to the

point of providing a viable prototype system for clinical testing of user acceptance.

Progress—The first system had a text-only diagnostic terminal, a four-line status display, and a simple speech synthesis system to convey information to the user. The only input was through the 58-word command vocabulary and a standard keyboard. The CPU was the relatively slow Z-80.

The first system's interface provided only rudimentary information flow; its users and researchers agreed that it was imperative to enhance all aspects of the technology. The second system will employ the powerful IBM PC-AT microcomputer, advanced speech I/O systems and displays, and an analog input system for cursor and robot motion control.

The software for the first system was written in PLZ, a PASCAL-like language for the Z-80 microprocessor, under Zilog's RIO Operating System. Although that language was flexible, the small size of physical memory and the slow speed of the Z-80 CPU limited the size and

speed of programs that could be developed. The second system's computing environment is Borland's TurboPASCAL, chosen for its fast compiler, efficient code generation, and excellent debugging environment. It allows for interrupt service routines to be incorporated into the main program body, which facilitates creation of software interfaces for peripheral devices.

Preliminary Results—The basic software architecture for the control of communications between the user and the mobile base has been established. A program has been written that

provides an interface to the IBM PC-AT for all the main peripherals, utilizing serial ports and interrupt-driven service routines.

Real-time software has been developed to display, in perspective, the world model of the mobile robot navigating a room containing several obstacles. Human factors literature, cockpit designs, and automobile dashboard layouts have been studied to aid in the design of a display that would represent the status of the mobile base as fully and effectively as possible. The software is currently being developed.

Design and Development of an Interactive Workstation for a Robotic Manipulation Aid

Gayle Curtis, M.S. and Karen Holloway, B.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The Veterans Administration/Stanford University Robotic Aid is currently undergoing second-generation development. The user of the aid, who will be acting in a "supervisory" role, will need real-time and reference information about the robot and the environment.

A human/robot workstation is needed wherein key specifications are based on the experiences of, and needs expressed by, users of the first-generation system. This new workstation must allow effective integration of the various input and output devices necessary to monitor and control the Robotic Aid and its peripherals. It must also be aesthetically pleasing and fit into the user's total environment.

The sensory capabilities of the Robotic Aid will be greatly increased, in second-generation development, to lessen the control burden on the user. The workstation will facilitate access for both disabled and able-bodied users, meet the needs of the technical development and clinical evaluation teams, and allow multi-user interaction and easy group demonstration.

The second generation lab system employs two LSI-11 computers and an IBM-AT. It also includes an improved speech synthesis unit (Dectalk), a voice recognition unit (Kurzweil), a six-degree-of-freedom manipulandum (VIDOF),

an ultrasonic head control interface (UCHU), a series of programmable switches, a keyboard and a video camera. VIDOF is used for six-axis control of the robotic arm, while the UHCU is dedicated to two-axis control of the mobile base and the graphics screen cursor. Current functions of the programmable switches include arm power control and an emergency stop button. The video camera mounted on the robot provides real-time visual feedback to the user. The mobile base houses one of the LSI-11 computers and communicates with the central processing unit through a radio link. A high-resolution graphics display is used, with a combined diagnostic display and video monitor.

We propose that an effective user interface to the Robotic Aid will result from meeting the following design criteria. 1) The user is given free choice between equivalent modes of command entry, with voice, keyboard, and "pointing" commands (VIDOF or UHCU) equally accessible. 2) A clear line of sight is maintained between the user and the mobile unit to facilitate monitoring of robot behavior and status. Information necessary for real-time control of the Robotic Aid, such as video images and graphic display of environmental data, is always displayed, whereas reference text and

diagnostic information are displayed only when they are called up by the user. 3) Flexibility in configuring these displays enables effective use of the robotic system in training, evaluation, and demonstration.

Progress—The first step in the design of this workstation was a literature and product search in the area of interactive human/machine systems. Topics ranged from telemanipulation and space station design to shared-attention environments and display devices. The product search included investigation of flat panel-display technology, touch screens, “knee-top” computers, and keyboards with infrared links. Device evaluation centered on power specifications, compatibility with existing equipment, human factors, size, weight, and cost.

The design of this workstation has been likened to the design of a vehicle dashboard. Both require that special attention be given to the forward visual field of the operator while maintaining the visual field of display, to hand (or mouthstick) reach for control action, and to knee and leg (or wheelchair) clearance for accessibility and comfort. An effort was made, in

the acquisition of anthropometric data, to address the physical needs of the greatest number of users while considering their visual and functional capabilities.

The first prototype (June 1985) was designed to be a complete piece of furniture with storage space, swing arms for the graphics and text display and video monitor, and a docking area for the mobile base. The second prototype (November 1985) featured two articulating arms for the monitors and minimal workspace for the user and the robot. The current design reflects a trend toward modularity. It is a tabletop system that can be affixed to a table of the user's choice. Components, such as the keyboard and the UCHU, can be moved around according to the user's preference, and then secured. The display and monitor are stacked, with the graphics display set into the tabletop unit, to reduce the overall size of the workstation. Iteration and refinement of design concepts are expected. The current prototype will initially be used with the laboratory system; after debugging and further development, the robotic system with mobile base and workstation will be transferred to a clinical setting for evaluation and user trials.

Safety Features Implemented on a PUMA 560 Robot Used in an Applications Setting

Gayle E. Curtis, M.S. and Roman Beyer, M.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The PUMA 560 is a robotic arm that is often used in industrial assembly situations. It is capable of movements that, potentially, could cause serious bodily injury to a person within its reach envelope. When such a device is used in a setting such as the Robotic Aid Laboratory, precautions are taken to restrict the hazards presented by the arm's movement, and the individuals working in the laboratory are informed of the dangers involved in working close to the robot.

When the robotic arm is taken out of the laboratory and put into an applications setting, the awareness and background of those work-

ing with the robot may not prepare them for the actual hazards that it presents. In addition, the setting itself may increase an individual's exposure to danger.

Using a robotic arm in a practical applications environment requires a serious review of the safety hazards presented and the features implemented to address them. The use of the PUMA 560 as a choreographic instrument in the dance performance “Invisible Cities” gave a unique opportunity for such a review.

Progress—The PUMA 560 was installed in a setting where the choreographic work for Invis-

ible Cities could be developed. A number of dancers and choreographers from the company ODC/San Francisco worked with the machine. Much of the choreography involved having a person inside the reach envelope of the robot.

To assure the safety of that person and everyone else working on the project, the following procedures were developed and applied: 1) limit the number of people who work close to or come in contact with the robot; 2) develop and present demonstrations of the hazards presented by the robot; 3) post and point out information about the robot's reach, power, geometry, and other safety-related specifications; 4) continually remind those working close to the robot of potentially hazardous positions, movements, or configurations; 5) mark clearly and visibly the extent of the robot's reach envelope, and indicate its significance; 6) restrict by directive the carrying of excessive loads by the robot that might cause failure of a servo or control; 7) restrict by directive specific human-robot configurations that could entrap an individual before the monitoring equipment or personnel could respond; and 8) maintain one person in the role of "safety monitor" (with one hand on the emergency-OFF button, this person watches for anomalies in the robot's movement whenever motive power is applied to the robot and a person is within its reach envelope).

In addition, the following hardware features were also implemented. 1) Contact sensors in the form of low-activating-force tape switches were installed on five faces of the robot's arm segments. These sensors provided a con-

tact-closure event that caused either a program interrupt in the robot controller, a shutdown of the robot high power, or both, and indicator lights showed when a tape-switch closure took place. 2) An additional emergency-OFF button was installed at the base of the robot within easy reach of anyone working close to the arm. 3) A deformable plastic-foam end effector was designed and built to cushion against any incidental contact with the end of the arm, and other parts of the wrist joints were covered with neoprene cushion to minimize the number of sharp metal edges to which personnel were exposed. 4) Contact microphones were installed inside two arm segments. These provided for redundant sensing and monitoring of arm motion. Even in the event of a controller failure, these microphones could provide information about the motion status and arm velocity.

Preliminary Results—The performance premiered on December 6 and 7, 1985, at Stanford University, without a single robot-related safety incident.

Future Plans—Further development of the safety system will explore the following: educating personnel more effectively, using redundant safety monitors, increasing the surface area of the robot that is capable of sensing contact, covering the entire robot with a cushioning material, and implementing a more sophisticated response system to both the acoustic and contact sensors installed on the robot.

Laboratory Robotic Arm Testing Environment

Marc Gimbrere, B.S. and Machiel van der Loos, Engr.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—A multipurpose laboratory environment is desired for the testing of software and hardware utilized by the Unimation PUMA 560 robot arm. The arm is being used as a testbed for the sensing and vision systems that will eventually be downloaded to the smaller mobile Robotic Aid.

Prototype testing procedures offer potentially erratic situations (such as hardware or software malfunctions in the testing regime) that could prove hazardous, dictating the need for a redundant safety environment that will shield the user from danger and also protect the arm's own end-effectors from damage.

We feel that development and testing time associated with the Unimation PUMA 560 arm will be reduced by the ability to focus all of the work into a physically defined yet flexible environment. Additionally, we feel that safety to the user and the arm will be enhanced by the features of the described structure.

Progress—The laboratory environment for the testing of the PUMA 560 robot arm consists of an 8-foot-diameter table fabricated out of three similar 120-degree sections. The top of each of these sections provides a rectangular cavity (approximately 20 x 36 x 3 inches) into which can be placed any desired type of testing module. Typical module options are: a light-table for vision systems work, a cushioned surface for ultrasonic proximity sensor testing, a grid surface for coordinate system testing, and a "Lego"-like surface for pick-and-place applications.

One of the three cavities provides a platform that is actually a dropaway surface into which a plug-in module can also be placed. The user dials in a maximum force level (from 2 to 50 pounds) and the dropaway platform, sensing the amount of force the robot arm (or any other item) is impressing upon its module surface,

will drop out of harm's way when the limit is exceeded. The purpose of the dropaway section is to provide a redundant safety feature that is out of the robot-software control loop. It is designed to provide an immediate reduction in resistance. However, it cannot withstand very-high-velocity shocks.

The remaining two cavities are static, though they may be upgraded to dropaway status if necessary. Under the table are cabinets for storage of the plug-in modules, the PUMA controller, the workings of the dropaway section, and various power supplies and random storage items. The cabinets house all of the dropaway controls, as well as highly visible panic buttons that are capable of cutting power to the robot, dropping the dropaway surface, or both.

Future Plans—The design of the PUMA 560 table, including electronics and control displays, has been completed. After the table has been constructed, the dropaway surface will be evaluated. Design changes will be implemented when necessary to support unforeseen testing needs.

Development of a Training and Reference Manual for a Robotic Manipulation Aid_____

Karen J. Holloway, B.S. and Edward Herrera

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The first-generation Veterans Administration/Stanford University Robotic Aid was developed to give individuals with high-level spinal cord injuries increased control through the ability to better manipulate their environment.

As part of the clinical evaluation of the Robotic Aid, a training and reference manual was developed to provide trainers and users of the device with standardized instruction and to communicate the features and intent of the system.

The need for directed training on this system is pronounced. The Robotic Aid is an interactive system requiring both a human op-

erator and machine intelligence and is intended for use in an unstructured human living environment. Since this system does not operate in the same context as a programmed industrial robot, more responsibility is placed on the user who must first decide what task is to be carried out and then guide the robot's motion explicitly, using his or her own sensory and decision-making capabilities. This necessitates a certain level of control expertise; not only must the user be familiar with the commands to which the robot responds, but he or she must also be able to anticipate the motions evoked by those commands.

Progress—The training and reference manual has evolved with the Robotic Aid Project. It began as a small set of training exercises and grew to include instructions ranging from how to start up the system hardware and improve command recognition, to suggestions for troubleshooting and information on the technical aspects of the system. The many different versions of the manual reflect the changes that have occurred in the 5 years of first-generation development. Its readers include technical and clinical researchers as well as experienced and first-time users of the Robotic Aid.

Preliminary Results—Various versions of this manual have been used in the training of more than 100 individuals. The tasks covered in the manual are designed to test an individual's mastery of particular command sequences. Many are based on needs expressed by the initial users of the system, e.g., the ability to get a drink of water. Other direct results of user feedback include a voice management program with options for training, updating, and saving a vocabulary and on-line instruction for recovery from error conditions. In both cases, user

autonomy has been increased, permitting greater interaction with the robot while lessening intervention by a supervisor or attendant.

Future Plans—Work on the training and reference manual for the first-generation Robotic Aid was suspended in 1984 with the funding of the second-generation proposal, Development and Evaluation of an Advanced Manipulation Aid for the Severely Disabled. The current (first-generation) edition of the manual will be used as a foundation for instructions and guidelines for the new system.

One format under consideration is a computerized version of the manual integrated into the human interface, such as an on-line "help" facility. Another would use interactive video technology. A master copy of the manual would be updated regularly so that a state-of-the-project report would always be available and a user could submit a request for a hard copy simply by saying, "PRINT." This option might include a perforated "cheat sheet" that would serve as a quick reference for experienced users and eliminate the need for the printed manual as an encyclopedia.

Evaluation of Robotic Aids for the Severely Physically Disabled

Karyl Hall, Ed.D.; Karen Glass, O.T.; Edward Herrera

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The concept of using robotics to provide increased functional independence for the disabled is not new, but to date little data have been published showing that specific tasks can be performed satisfactorily within a reasonable period of time. At present, no robotic aid for the disabled has made it from the laboratory to the marketplace.

It is hypothesized that repeated evaluation by disabled users and continued improvement of present technology based on these users' feedback will make robotic devices and interface controls for the disabled practical, cost-effective, and generally available.

This project is an expansion of a study that investigated the use of the robotic aid for

eating and hygiene tasks. The robotic aid being evaluated is a Unimation PUMA 260 industrial arm, augmented by an IBM PC/AT and a Keytronics Voice-Input Keyboard Emulator. A workstation surrounding the robot arm makes accessible the materials needed for functional tasks. Within reach of the arm are a computer terminal, a microwave oven, a refrigerator, disk drives, and a two-way speaker phone.

A freestanding kiosk on a rotating base holds supplies for activities of daily living (hygiene and grooming), for vocational and recreational activities, and for feeding. One of the four sides of the kiosk is exposed at a time, the others being concealed by the casing.

Individuals with high-level quadriplegia

(neurological levels C3 and C4) and no arm or hand function are learning to operate the robotic arm by means of voice commands to complete tasks such as brushing hair, washing the face, brushing teeth, eating a meal, preparing food, playing boardgames, retrieving objects, shaving, and word processing. Subjective and objective measures of user satisfaction include time to complete task, thoroughness, ease, and other outcome measures specific to each task.

Preliminary Results—A self-instruction manu-

al on the use of the robotic arm has been written. Functional tasks have been evaluated subjectively by various user groups. Improvements have been made to the system based on user feedback; for example, a new command program is being written on the PC/AT to allow more flexibility in user interface strategies.

The workstation and kiosk are presently being assembled for a more comprehensive, objective evaluation and an improved level of utility for the robotic aid.

Eating and Hygiene Tasks for the Robotic Aid

David J. Cannon, M.S. and Edward Herrera

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Central to the goal of enabling people with quadriplegia to control their surroundings independently is the challenge of assisting them in fulfilling their needs in everyday living. Two areas are of particular importance: eating and hygiene. Persons with quadriplegia should be able to perform these tasks by themselves with the help of the Stanford/VA's Robotic Aid.

The problem addressed here is to design the environment and write the needed application software to accomplish this goal. Methods used to develop these particular applications for the Robotic Aid are themselves generic. Other tasks, particularly in the vocational and entertainment areas, can be modeled after concepts developed here.

Over the past 3 years the Robotic Aid has been programmed for a variety of food preparation and personal clerical tasks. However, none of these demonstration programs were refined to the extent needed for routine usage in a daily living format. The Robotic Aid has always been "interactive" in the sense that the user can change the movement, pattern, and objective of the manipulator at any time, but these capabilities have not been fully explored in the context of allowing direct contact between the user and the robotic arm.

Progress—By making full use of both the clinical and engineering expertise available in the Stanford/VA environment, several key eating and hygiene tasks were defined. After producing full scenarios of each eating and hygiene task, a team of engineers, therapists, and users programmed the Robotic Aid to perform the desired subtasks. Special emphasis was given to having actual quadriplegic persons involved at all stages of programming and development.

The VAL programming environment was used to write the robotic arm routines, while the VOTERM was used for voice recognition and ARMC was used to implement the voice commands.

Preliminary Results—The original scope of this work was successfully completed in the summer of 1985, and the results demonstrate that the Robotic Aid can be used effectively by individuals with quadriplegia to groom and feed themselves in a routine manner. Such individuals are now able to use voice commands to direct the Robotic Aid to wash their face, brush their hair, feed themselves a three-course meal, and brush their teeth.

Videotapes are available to show these tasks being performed by an individual who does not have functional use of his arms and legs because of quadriplegia.

The Role of Choreographic Exploration in the Design of the Robotic Aid

Gayle Curtis, M.S. and Margo K. Apostolos, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—A robot intended for human service applications faces challenges that differ from those of its industrial counterparts. A machine that must share a living space with its human user needs to account for the quality of its character as well as its capabilities. In a robot, character arises from its form, scale, finish, sound, and other elements.

A particular feature of the robot is the way that it moves, and the quality of that movement is a very distinctive part of its character. Any comprehensive approach to the design of the Robotic Aid must also include the design of its movement.

To support this approach, more information is needed about how quality of movement affects the overall character of the robot and how this quality bears on the user's acceptance of the robot as an assistive device. Much of the functional effectiveness to be delivered by the Robotic Aid will depend on the positive attitude of the user and the user's willingness to learn and explore with the machine. Could not a machine that is awkward, or intimidating to use, needlessly discourage a person in a real living situation?

Progress—Exploration in the expressive, aesthetic use of the robot arm began in 1978, with "Ballet for One Arm." In that work, the PUMA 250 was programmed to move with graceful precision in synchronization with a piano composition. Audiences still respond enthusiastically to videotapes of the piece, and their enthusiasm has encouraged more exploration.

Work begun in 1982 and continuing over a period of 3 years developed a robot choreography that demonstrates the machine's expressive potential.

To encourage an extensive further exploration into the design of aesthetic movement and the varieties of movement character, the Robotic Aid Project has now participated in a col-

laboration to mount a full-scale performance of computer-music, dance, and robot choreography. A liaison was formed with composer Michael McNabb, Stanford's Center for Computer Research in Music and Acoustics, and Brenda Way, artistic director of the dance company, ODC/San Francisco.

For this performance a large robot arm, the PUMA 560, was selected because it promised a more effective stage presence than the smaller PUMA 250. Over a period of 4 months, four individuals worked intensively to design and program choreographic sequences for the robot. Dance professionals Brenda Way and Julie Kanter were trained in the use of the robot teach-box and the VAL programming language. Each person worked to explore the expressive capabilities of the arm, keeping in mind the musical score being written and the overall concept of the piece. In many cases, the robot's movement was designed to relate closely to the movement of a single dancer.

A theme was developed around the notion of a "dialog" between the robot and a human dancer. The robot, as a character in the performance, was called upon to show recognizably different "moods." This naturally led to exploration of the range of expression that the machine could be programmed to display.

More than 1 hour of choreographic material was developed, of which approximately 40 minutes were finally selected for the performance. The work comprises five distinct movements and demonstrates a wide range of expression. The finished work, "Invisible Cities," was performed with 13 dancers, 2 musicians, and a robot programmer. The premier performance was at Stanford University on December 6 and 7, 1985. Critical reviews were favorable.

Future Plans—Two lines of future work are indicated. The first is to continue the assessment of the influence of perceived aesthetic move-

ment on the user's acceptance of the robot. The second is to develop a series of utilitarian tasks to be performed by the robot using distinctly different movement styles: Might a Martha Graham fetch a glass of water in a way different from that of a Charlie Chaplin? Is there a value in giving the user a choice as to the kind of character his or her own robotic aid might have?

Once a fluency in the expressive ability of

the robot can be demonstrated, access to that ability could be extended to the user. How often do we show emotion or intention by the way we set down a plate or pick up a cup? Those simple expressive gestures may be denied, today, to an individual with limited motor or manipulative abilities. But, with access to a choreographic vocabulary in the robot, the user might gain a rich medium for gestural expression.

Aesthetic Implications of Robotic Movement: A Case Study

Margo K. Apostolos, Ph.D. and Larry Leifer, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—User acceptance of assistive devices has been a chronic, significant problem in the introduction of new technology for the disabled community. In the case of the Stanford/VA Robotic Aid, the character and the aesthetics of motion could be a factor in user acceptance. This study addresses that problem.

Progress—As a part of the Rehabilitation R&D Center's Robotic Aid Project, an industrial robotic arm was programmed for use by quadriplegics as a personal assistant in a rehabilitation setting. During actual use by the research staff and other subjects, it became apparent that some programs resulted in movements that were jerky and awkward, while others resulted in movements that were smooth and graceful. It was perceived that the graceful movements positively influenced the users' feelings about interacting with the robot.

It is proposed that aesthetic (i.e., choreographed) movement of a robotic arm can favorably affect an individual's attitude about accepting and using a robotic aid. It is further hypothesized that the provision of an aesthetic component in the user's orientation to the robot can, of itself, have a very favorable effect on user acceptance.

The focus of the project was an assessment of attitudinal changes shown by selected individuals with quadriplegia, in response to the presentation of two different orientation programs on the use of a robotic arm. One program included a discussion of aesthetic sequences of robotic movement, industrial design, and kinetic art. In contrast, the other program presented the "standard" introduction to the robotic arm, which involved utilitarian sequences of robotic movement.

A questionnaire was administered before and after the orientation sessions. An exploratory follow-up study was conducted on one of the subjects actually trained to use the robotic arm.

Preliminary Results—A doctoral dissertation on this preliminary study of aesthetic training was completed and submitted to Stanford University in December 1984. Results of the study were inconclusive because of the extremely small sample populations, but were suggestive of the proposed effect.

Future Plans—A pilot project has been proposed in which the arm will be programmed for utilitarian tasks utilizing aesthetic movements.

Development of Environmental Control Units for Disabled Veterans

Mark I. Bresler, M.S.

Veterans Administration Medical Center, Oklahoma City, OK 73104

Sponsor: VA Rehabilitation Research and Development Service

Progress—This project had two goals: 1) to further develop an environmental control unit (ECU) for use in hospitals and long-term care facilities; and 2) to determine if new developments in home electronic equipment are applicable to disabled individuals. (This project was a continuation of an earlier one conducted by Bresler, "An Environmental Control Unit for Rehabilitation Hospital Use," reported in *Proceedings of the Second International Conference on Rehabilitation Engineering*, Ottawa, Canada, p. 605.)

Using much of the same hardware and software the ECU would be repackaged in a smaller display box and would also use different interface circuits to enhance the data integrity of communications between system subsections. Some standards work at the Electronic Industries Association might be applicable to ECU users. The Electronic Industries Association Consumer Electronic Bus Technical Steering Committee is studying remote controls for in-home applications and monthly Committee re-

ports were reviewed during the project. The Committee is concerned about interference between existing remote control systems and would like to establish standards allowing consumers to control several devices from different manufacturers with one remote control. Although progress has been made in studying existing systems, no control standards have been developed to date.

Development of a standard would greatly simplify ECU design. The ECU developer would need only to design a controller, eliminating the need to modify each controlled device. If these standards are developed, a controller could be developed either by modification of control units for the general population or design of a new unit. In this way an ECU user in a hospital setting could become familiar with consumer items for use after leaving the hospital. At the present time, a hand wired control unit and slave unit have been constructed. Continuation of this research has been left to ECU manufacturers.

Analytic Techniques for Automated Grasp

John W. Jameson

Department of Mechanical Engineering (Ph.D. dissertation abstract), Stanford University, Palo Alto, CA 94305

Sponsor: Palo Alto Veterans Administration Rehabilitation Research and Development Center

Purpose—As the application of robotics in industry and other fields moves towards greater flexibility, the need for systems with enhanced sensory capability and algorithms with greater generality is becoming apparent. One important aspect of automatic manipulation is the establishment of a secure grasp of an object. The ability of robot manipulators to securely grasp objects, without human supervision, shall be essential for the "intelligent" robots of the future.

This thesis first attempts to analyze conditions for which stable grasping occurs. A review

of mathematical models for contacts leads to the selection of point contacts (with friction) as the primary model for study, and "soft finger" contacts as a secondary model. Conditions for stable grasping are given for statically determinate systems in which all forces are known for a given load on the object. A more general approach, called quasi-static analysis, is presented which can predict the stability of a large class of statically indeterminate, as well as determinate, systems.

The second part of the thesis explores the possibility of automating grasp by considering

the process of finding secure grasps as an optimization problem. The first step in accomplishing this is the establishment of suitable goal functions which reflect the stability of the grasp. Secondly, constraints are needed to keep the gripper away from undesirable configurations. The resulting constrained, non-linear, op-

timization problem is then considered for two- and three-dimensional simulations. The results of the simulations indicate that the method is particularly effective when the gripper is initially close to the desired position, although effective grasps can often be found even when this is not the case.

The Application of Continuum Methods to Path Planning

Charles E. Buckley

Department of Mechanical Engineering (Ph.D. dissertation abstract), Stanford University, Palo Alto, CA 94305

Sponsor: Palo Alto Veterans Administration Rehabilitation Research and Development Center

Purpose—Most algorithms which have been developed to solve the path planning problem are based on a mapping of a given problem into a finite state space. While this *combinatorial* conversion always results in a problem which can ultimately be solved by a computer, the computational complexity of transformed problems which accurately reflect their continuous counterparts can be prohibitively high.

By contrast, certain previously developed algorithms did not follow this approach. These algorithms worked directly with the continuous problem space, and are called *continuum algorithms* in this report. These *continuum* algorithms were relatively unsophisticated when compared to the more popular combinatorial methods, yet their results were good.

This observation served as a motivation for the research reported here, in which it was sought to provide continuum algorithms with a

more rigorous theoretical base. The main result of this work is the development of a real-valued function which characterizes the proximal relationship of two non-point convex bodies. This function is different from similar functions reported previously in that it also provides useful information when the sets under consideration intersect.

In this document, the need for such a function is established, and certain computationally useful properties of the developed function are proven. Efficient means for its computation for polyhedral sets are developed, and the algorithms for this are presented. These results are subsequently used in a path-planning algorithm based on numerical relaxation. Results of comparing the performance of this algorithm with that of Brooks' planar free-body path-planning algorithm are presented.

Computer Methods in Manipulator Kinematics, Dynamics, and Control: A Comparative Study

Charles Weldon Wampler, II

Department of Mechanical Engineering (Ph.D. dissertation abstract), Stanford University, Palo Alto, CA 94305

Sponsor: Palo Alto Veterans Administration Rehabilitation Research and Development Center

Purpose—The objectives of this research were:

- 1) Design and develop efficient algorithms for manipulator kinematics and dynamics, including inverse kinematic solutions, actuator torque computation, and equations of motion for simulation.

- 2) Investigate the reduction in computation

that can be obtained when the manipulator fits the assumptions of a restricted model incorporating simplifications common to most industrial manipulators, and estimate the reduction that can be anticipated when the equations are worked out symbolically by doing so for a model of the Stanford Arm.

3) Analyze the singularities that can arise in inverse kinematic solutions and develop efficient means of dealing with their presence.

4) Present stability proofs for several control schemes, including the conventional joint servo, computed-torque control, resolved-rate control, and resolved-acceleration control.

5) Compare the expected performance of the conventional joint servo and the computed-torque servo in computer simulations of the Stanford Arm.

The principal contributions of this dissertation have been: the development of efficient computer algorithms for inverse velocity/angular velocity solutions, inverse acceleration/angular acceleration solutions, actuator torque

computation, and equations of motion for simulation; the introduction of damped least-squares formulations to eliminate singularity problems in inverse kinematic solutions; a comparison of algorithms based on Kane's equations of motion to previous formulations based on Newton-Euler methods; an investigation of the reduction in computation that can be obtained for manipulators meeting certain restrictions; stability proofs for improved versions of the resolved-rate controller and the resolved-acceleration controller that account for singularities; and a comparison via simulation of the conventional joint servo against the computed torque servo.

G. Wheelchairs, Including Seating and Controls

University of Virginia Rehabilitation Engineering Center

Warren Stamp, M.D.; C. A. McLaurin, Sc.D.; C. Brubaker; J. J. Kauzlarich; J. Thacker; R. Inigo; J. Aylor
Rehabilitation Engineering Center, University of Virginia, Charlottesville, VA 22903

Sponsor: *National Institute of Handicapped Research*

Progress—The Rehabilitation Engineering Center (REC) is in the fourth year of a 5-year program, conducting research on wheelchairs and seating for the disabled. Some of the seating studies are contracted to the University of Tennessee Rehabilitation Engineering Center at Memphis.

The emphasis at REC is to conduct technical studies on all aspects of wheelchair and seating design and function that will lead to a better understanding of the principles involved and hence contribute to improved design, fabrication, and prescription.

Progress—Recent work on specific tasks includes the following:

1) The dynamometer used for wheelchair propulsion studies has been completely rebuilt, allowing greater accuracy and quicker adjustments. The system includes a method for recording arm position in three dimensions by

means of wands that are attached to the arm with Velcro straps. The position of the wands is recorded by potentiometers. Speed, power, and instantaneous torque using handrims or levers have been retained. All data are analyzed by computer. Included among the various studies is development of a computer program to predict the most effective seating position and propulsion system for an individual based on a few simple measurements and projected usage.

2) The effect of seat and back angle on pressure patterns and cushion contours has been recorded for a number of persons with spinal cord injury. The information will be used in design and prescription related to seat contours and configurations.

3) The effect of seat and back position on the functional ability of persons with cerebral palsy has been studied by colleagues at the University of Tennessee in Memphis. Anthropometric data collection has continued at Mem-

phis and Charlottesville.

4) The effect of pressure patterns on tissue deformation is being investigated using magnetic resonance imaging.

5) A caster shimmy friction damper has been designed and fitted to a number of wheelchairs for testing before manufacturing.

6) Stress analysis studies have focused on low-frequency fatigue failure, as a suspected mechanism of failure in wheelchair frames.

7) A double drum machine for fatigue testing wheelchairs has been designed and constructed for use in test procedures of the International Standards Organization and the American National Standards Institute.

8) A theory for "wheelies" has been conceived and developed.

9) Battery studies have concentrated on the tubular positive plate design. The technology is available to produce such a battery in gel form that would last four times as long as conventional deep discharge batteries at a cost increase of about 50 percent. This could result in savings of up to \$6 million annually.

10) A battery monitor that eliminates the false readings due to power surges has been designed. Work on a microprocessor design to yield accurate energy levels for any type of battery continues.

11) The investigation into fault-tolerant powered wheelchair control systems has been initiated.

12) The adaptive controller has been simplified to a selective controller and installed in an Invacare Rolls powered wheelchair. Testing of algorithm options continues.

13) A wheelchair data logging system has been completed.

14) A motor controller has been designed to convert a 24-V supply to an output varying from 15 to 40 V. Test results are encouraging.

15) Several wheelchair designs are being considered by manufacturers for production. These include the NASA/UVA composite wheelchair, the lever drive, and a new design that folds to a very compact package with the main wheels removed and allows instant adjustment in seat position while seated.

Development of a Linear Synchronous Motor for Wheelchair Use

Gary W. Kelly, B.Psych.; David A. Ross, M.Ed.; Richard M. Bass, M.S.E.E.; Kent R. Davey, Ph.D.;
Rehabilitation Research and Development Unit, Veterans Administration Medical Center, Atlanta, GA 30033
Sponsor: VA Rehabilitation Research and Development Service

Purpose—The Linear Synchronous Motor (LSM) is a wheelchair drive system designed to take advantage of recent high-technology advances in motor controls. The goal is to implement a wheelchair drive system that is less expensive, is more efficient, requires less maintenance, is lighter weight, and will perform with optimum efficiency at any speed on any terrain. This motor will be built into the circumference of the large wheelchair wheel. The wheel becomes the rotating member or rotor of the motor, and the coils that control this rotation or stator will be mounted onto the frame. Thus, the only moving part in this system is the wheel itself. It is intended that this system will eventually become an integral part of an "intelligent" computer-controlled drive train for powered wheelchairs.

The purpose of the current research was to design, build, and bench test a single LSM motor on a wheelchair wheel. In addition, a computer simulation model of the motor was to be developed.

Progress—The computer simulation of this motor was developed on the Hewlett-Packard Model 310 microcomputer. Full computer-aided designs were developed on the HP 9920 CAD system utilizing HP Draft and EGS 200. After preparation of the working drawings, the initial controller was constructed.

The controller was based on the Motorola 6809 microprocessor. A commercially available board was utilized and the power board was added to provide three-phase pulse width modulation current control. The initial control

system tested successfully and work proceeded on the motor itself.

A bench prototype was constructed using a solid aluminum base, bearings, a 20-inch-diameter rotor, and matching stator, which comprised one-half the rotor area. In addition, the rotor shaft extended through the test bed frame and connected to a pneumatic brake. The end of the shaft connected to an optical encoder to send a digitized signal to the microprocessor. This arrangement not only provided the processor with essential information as to the orientation of the rotor with respect to the stator, but also permitted exact monitoring of the motor's rpm under all loading conditions controlled by the brake. The system functioned successfully and fulfilled all expectations in March 1986. The measured efficiency was within 0.45 percent of the projected efficiency based on computer modeling. Projections indicate that a second-generation machine would be able to achieve more than 90 percent efficiency and deliver torque at low rpm to exceed published figures for wheelchair needs.

Designs have been revised and a new proposal submitted. When funded, a 3-year pro-

gram will begin to develop an optimal LSM, install working units on an existing chair, and after acquiring further test data confirming expected performance, design an initial prototype vehicle of a new conceptual design. The LSM appears to be an ideal motor for vehicle applications, and initial cost estimates are favorable.

Future Plans—Present progress on the LSM has consisted of refinements to the control system and a design for an improved stator having more windings on an iron core. Further test data will be gathered in the time elapsing until further funding can be procured.

When further funds are available, an optimized motor design will be implemented and a pair of such motors using rare earth magnets will be produced. These units will be tested on existing power wheelchairs to determine specific problems in control and motor design for this application. The inherent reliability of LSM and low maintenance combined with the high efficiency and design simplicity offer much freedom in vehicle design. The research team plans to implement a power chassis design as outlined in *Wheelchair III* in the third year.

Developing Safety Standards for Wheelchair Occupants in Vehicles

W. E. Fisher, Ph.D. and B. R. Seeger, Ph.D.

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: S.A. Department of Transport and Design Arts Board of the Australia Council

Purpose—Testing of vehicle restraints for wheelchair occupants has revealed that commonly used methods are unsafe. Previous work at Regency Park Centre for Young Disabled led to the development of a crashworthy restraint system for wheelchair occupants. More recently, the issue of safety standards has been addressed.

Progress—The following initiatives were undertaken to overcome these difficulties:

- 1) An illustrated booklet, *Wheels on Wheels*, was published to inform prospective users and buyers of the need for restraints, the choice of suitable wheelchairs, and related safety issues. (The booklet is available free on

request from Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, P.O. Box 209, Kilkenny, S.A. 5009 Australia)

- 2) An informative videotape, similar to the booklet in content, is available on VHS cassette (PAL System, price \$30 Australian).

- 3) A "Draft Australian Standard: Wheelchair Occupant Restraint Assemblies for Motor Vehicles," was distributed for public comment in May 1986. Copies may be obtained from The Standards Association of Australia, 80 Arthur Street, North Sydney, NSW 2060 Australia.

These developments towards better standards will provide protection for wheelchair occupants traveling in vehicles and facilitate

transport of severely disabled people.

Optimal Biomechanical Design/Development of Arm-Powered Mobility Devices

Michael Zomlefer, Ph.D., and Douglas Schwandt, M.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Individuals with lower limb disorders are looking for more optimal solutions to their mobility and exercise needs. Through such improvements, they could enjoy the quality and degree of independence and societal integration to which they are entitled.

Few alternatives to conventional wheelchair handrim propulsion are currently available and precious little research has been done to fine-tune the rider to his mobility aid. A need exists to design better arm-powered drive systems which are ergonomically optimal, functional, and economically feasible for device development.

Modern control theory, when coupled with human biomechanical performance measurements, could lead to nearly optimal arm-powered drives for use in mobility vehicles and stationary exercise machines for the disabled. This would involve the development of a tractable, computerized, biomechanical model for the upper limb as it applies to a broad spectrum of arm-propulsion tasks. Given specified performance criteria (such as maximum power output or maximum efficiency), this model could then be used to create optimal configuration and dimensions for any proposed drive system and purpose.

In the approach adopted here, experimental results obtained from subjects operating a

variety of arm-powered ergometer drive systems will be used to help define and refine the biomechanical model of the upper limb performing optimal ergonomic tasks, applying modern optimal control theory. In order to develop a more universal mathematical model, several drive and load systems will be employed, each with such variable features as crank length for arm-cranking experiments or lever length and pivot position for oscillating lever propulsion. Kinematic and dynamic data will be acquired and analyzed with simultaneously collected electromyograms (EMGs).

Progress—The laboratory arm-powered ergometer has been designed and is under construction. Progress is being made on linear and eccentric-trajectory drive system designs (including application of the Kallander tapered belt drive) for use in subsequent experiments. Design work is carried out using the computer-aided design facilities at the Stanford Center for Design Research.

Mathematical equations of motion describing the dynamics of the arm-cranking task have been developed and are being entered into the computer. Dynamic and MG data acquisition systems are being assembled in preparation for the initial round of experimentation and analysis.

Powered Wheelchair Performance

William E. Fisher, Ph.D. and Barry R. Seeger, Ph.D.

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia.

Sponsor: Regency Park Centre for the Young Disabled

Purpose—Many disabled children need a powered wheelchair to achieve independent mobility. The number of children at this Centre using

electric wheelchairs has increased from 2 to 87 in the past 9 years. They need a safe, reliable wheelchair. Currently, however, there are no

standards or laboratories in Australia for testing the performance of wheelchairs, and consequently the incidence of breakdowns is high. An internal report at the Centre indicates that annual maintenance costs on some makes are up to 30 percent of the purchase price. Both the reliability of electric wheelchairs and wheelchair stability for safe outdoor use need to be improved.

This project's goals are to conduct performance measurement studies on electric wheelchairs and to use quantitative procedures to improve client/wheelchair matching, using results from the above.

Future Plans—In the preliminary phase, a data measuring and logging system will be pur-

chased, adapted, and mounted on an electric wheelchair, and an adjustable ramp will be built for testing the static and dynamic stability of wheelchairs. During the experimental phase, the data logger will be used to analyze patterns of wheelchair usage, which will be related to problems experienced in wheelchair use. The results of this study will be made available to the Standards Association of Australia and a professional scientific journal. We will work with wheelchair manufacturers to improve the design of electric wheelchairs and control interfaces.

This project will ultimately result in the establishment of an Australia-wide wheelchair testing facility at the Regency Park Centre for Young Disabled.

Wheelchair Controls

A. I. Tew, B.Sc. and J. D. Harris, C.Eng.

Oxford Orthopaedic Engineering Centre, University of Oxford, Nuffield Orthopaedic Centre, Headington, Oxford OX3 7LD, U.K.

Sponsor: Department of Health and Social Security, Great Britain

Purpose—Development is being carried out on a "proportional" wheelchair control that will provide smooth acceleration and balanced steering. The system is intended to have a range of input control options to suit a wide range of severely disabled people. The system is also intended to be interchangeable with the conventional controls issued with the normal range of wheelchairs.

Progress—A number of head controls for quadriplegics have been investigated, one operating on a positive pressure system in which the tongue is used to block off one of the four sensors. A control switch is triggered by the resulting back pressure. Being investigated is another noncontacting system that utilizes a retroreflector fitted to the patient's head and an infrared emitter-detector fitted to the wheelchair.

Three-Wheeled Vehicle

John Buckley, M.S.M.E. and J. C. Laederach

Volunteers for Medical Engineering Inc., Lutherville, MD 21093

Sponsor: Volunteers for Medical Engineering, Inc.

Progress—The Volunteers for Medical Engineering, Inc. (VME), working with a basic design from a client, has produced a very powerful and versatile vehicle. It includes in its design features a dual-motor power application selectable by the user and a multiple-speed manual transmission.

The first prototype of the design was fabri-

cated and made ready for its first powered ride in June, 1986. Documentation exists for many of the parts so that the next unit will be more readily fabricated. Efforts are now underway at VME to purchase parts in England for building a second model to test and evaluate.

Future Plans—The team working on the proto-

type will prepare an instruction manual and parts list for the design so that recipients of one of the models will be able to operate and maintain the unit.

The servo mechanism for the operation of this vehicle can be improved by the dedicated effort of the volunteers. However, the VME will be actively pursuing funding to allow the servo

electronics engineers to complete the redesign in a timely manner.

The vehicle is expected to out-perform all the three-wheeled electric vehicles on the market. The performance parameters will be documented for such a comparison. The aerodynamics and the aesthetics of the next model will also be given more attention.

Steiner Tractor Modification

James Fawcett, B.S.M.E., B.S.E.E. and Lance Shum, Ph.D.
Volunteers for Medical Engineering, Inc., Lutherville, MD 21093

Sponsor: *Volunteers for Medical Engineering, Inc.*

Purpose—The Steiner Tractor, made specifically for a paraplegic, can be used without modification by a person who has good upper body strength. The Volunteers for Medical Engineering, Inc. (VME) has modified the tractor so that a person with little or no upper body strength can operate it. Modifications include powered motion of the steering mechanism, and powered engagement, actuation, and disengagement of the automatic transmission.

Progress—The Steiner Tractor has been adapted with the powered steering actuation and with the powered engagement of the automatic transmission. The controls for the operation of these mechanisms will be client-specific, thus the first to be incorporated in the design is the chin controller developed by the Johns Hopkins Applied Physics Laboratory. VME plans to secure the license for this and other similar applications. Another proportional control device

developed by VME for use on a powered wheelchair by a person totally paralyzed from a stroke will also be implemented on the tractor. It operates via Morse code-type inputs using client thumb motion only.

Future Plans—Proposals are being written seeking funds for the timely completion of the total adaptation for the first two control systems and for further development of the addition of sensor controls to allow the tractor to be operated by anyone capable of operating a joystick.

We will develop the means for someone to automatically lock himself into the tractor bed so that he can perform more of the operations of entering and running the tractor, as well as a number of techniques for the emergency deactivation of the drive and power of the tractor as backup for the prototype system.

Seat Cushions for the Paralyzed

Bok Y. Lee, M.D. and Leon Bennett, M.A.E.

Surgical Service, Veterans Administration Medical Center, Castle Point, NY 12511; Manhattan Veterans Administration Hospital, New York, NY 10001

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—This project was undertaken to 1) evaluate the role of shear in pressure sore causation, 2) monitor paraplegic sitting reaction to assess buttocks blood flow characteristics, and 3) develop an instrument capable of sensing

buttocks blood flow.

Having determined that seated paraplegics, on average, evidence a smaller amount of cutaneous pulsatile blood flow than do normal subjects, we moved to determine the underlying

reasons. The reduced blood flow may imply unfavorable loading owing to an inappropriate posture, not sensed by the paraplegic, or it may suggest a reduced circulatory capability, possibly resulting from neurotrophic considerations or years of atrophy.

Progress—To study this matter experimentally, the waveform analysis method developed by Strandness has been incorporated into our existing apparatus. Harmonic analysis of plethysmographic waveforms permits a separation of that blood flow reduction owing to externally applied load, from that due to inferior natural circulation.

Twenty-one normal subjects (average age, 47) recruited from staff members and hospital patients with ailments other than paralysis or outer extremity circulation impairment, were tested in the vicinity of the ischial tuberosity while seated. They displayed a second harmonic relative to the fundamental, of mean value 0.34 with a standard deviation of 0.09.

Twenty paraplegic subjects (average age, 47), recruited from outpatients and volunteers and accepted without concern for other ail-

ments, have been divided into two subgroups—those with peripheral arterial deficiency as indicated by conventional Doppler segmental blood pressure testing ($N=7$) and those who have a normal peripheral arterial circulation ($N=10$).

Preliminary Results—Our results indicate the median paralyzed subject in sitting manifests a second harmonic strength roughly 20 percent less than that of the normal. Next, those who are both paralyzed and deficient in peripheral arterial circulation exhibit a wide range of buttocks blood flow characteristics as a function of thigh pressure. High thigh pressure is associated with a well-perfused buttocks, large second harmonic values, and lack of pressure sores. Low thigh pressure is associated with a poorly perfused buttocks, low second harmonic values, and the presence of pressure sores.

These results are presented as work-in-being. The indicated trends are supported by limited and even fragmentary data.

Future Plans—Our plans are to fully document those tentative trends given above.

Remote Monitoring of Pressure Relief Activity and Sitting Asymmetry in the Wheelchair User

M. W. Ferguson-Pell, Ph.D.; T. G. Burn, M.S.; D. E. Hurwitz; R. D. Masiello; M. Cardi, R.P.T.
Orthopaedic Engineering and Research Center, Helen Hayes Hospital, West Haverstraw, NY 10993
Sponsor: *Walter Scott and Lyons Foundations, and New York State Department of Health*

Purpose—Regimens for pressure-relieving activities (PRA) such as pushups and weight shifts to prevent pressure sores among wheelchair users are widely prescribed, but compliance is thought to vary considerably among individuals. Objective studies confirming that pressure sores are prevented by PRA have not been undertaken and the frequencies of movements prescribed are simply clinical rules of thumb of unknown origin.

Progress—Previous studies monitoring PRA have been undertaken in the hospital environment due to the limited memory and power capacity of the instrumentation used. Most pres-

sure sores caused by prolonged sitting in a wheelchair occur, however, in the home and workplace. In this study, we developed an instrumented seat-board that functions as a force plate and is connected to a purpose-built low-power signal conditioning and microcomputer package. This battery-driven system will operate for well in excess of 30 days without the need for any user or operator interaction. The device detects full weight relief and lateral and forward weight transfers. In addition, the position of the client's center of pressure is sampled periodically to detect asymmetric sitting behavior causing excessive loading of tissue on one side of the body. We anticipate that the causes

of asymmetry in many clients can be attributed to environmental factors (e.g., ergonomics of home and workplace) rather than musculoskeletal deformities alone. The force plate replaces the sling seat of the wheelchair and is mounted on adjustable drop-hooks providing the user with a normal sitting height. The force plate is readily removed to allow the chair to be folded and stored. The total weight of the system is 4.1 kg.

Display software has been developed to allow raw data that are stored on the portable unit to be transferred to a personal computer and displayed for clinical interpretation and

evaluation.

Future Plans—The next phase of this study will employ ten units to: 1) determine the frequency and variation of PRA in spinal cord injured wheelchair users; 2) establish whether sitting asymmetry is frequently encountered and attributable to ergonomic factors; and 3) allow comparison of PRA and sitting asymmetry between two groups of spinal cord injured wheelchair users—one group with a history of ischial breakdown and a group with no history of breakdown attributable to prolonged sitting.

Wheelchair Seating Effectiveness

William E. Fisher, Ph.D. and Barry R. Seeger, Ph.D.

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: *Channel 10 Children's Medical Research Foundation of S.A.*

Purpose—Many disabled children spend a large part of each day seated in a wheelchair, and need comfortable, supportive seating that meets their functional requirements. Inappropriate seating is a major contributor to the problems they experience in balance and comfort. Widely accepted seat guidelines in cerebral palsy have not been scientifically validated. New seating systems have become available, but their effectiveness has not been objectively assessed.

Our goals are to develop a standardized fitting protocol and outcome evaluation procedures for wheelchair seating systems in terms of cost, comfort, cosmesis, and function, and to evaluate six new special seating systems using the protocol established.

This project will result in improved seating for disabled children, at this Centre and else-

where in the world.

Progress—In the preliminary phase, protocols have been developed for the fitting of seating and the comparison of alternative special seating systems. Several new seating systems, such as matrix supports and foam-in-place methods, have been obtained.

In the experimental phase, cerebral-palsied children have been fitted with special seating systems, and each will be evaluated over a 3-month period from the date of fitting.

The results of the project evaluation, which will include prescription criteria, will be published in a professional scientific journal, and an instructional course on modern seating techniques for cerebral-palsied children will be conducted.

CUSHFIT: An Expert System for Wheelchair Cushion Prescription

M. W. Ferguson-Pell, Ph.D.; D. E. Hurwitz; M. Cardi, R.P.T.; G. V. B. Cochran, M.D.; V. R. Palmieri

Orthopaedic Engineering and Research Center, Helen Hayes Hospital, West Haverstraw, NY 10993

Sponsor: *Walter Scott and Lyons Foundations, and New York State Department of Health*

Purpose—Correct prescription of a wheelchair cushion is an important requirement for many wheelchair users, especially those vulnerable to

pressure sores. Careful matching of clinical characteristics, personal preference, and cushion properties is required for a successful out-

come. This is a skillful process requiring a systematic selection of candidate cushions based on a set of observations and measurements. The number of centers employing advanced cushion-fitting procedures is limited because of difficulties in transferring expertise and the specialization needed to provide these services. Cushion fitting is, however, ideally suited to an expert systems approach whereby a computer program allows a person with average expertise to function as effectively as a specialist.

Progress—The program CUSHFIT has been developed. The clinician uses the program to collect clinical information and feedback from the patient as the fitting process proceeds. Measurements of pressure are made by the therapists and input to the program. Goal pressures for each body site are established based on the existing skin condition and the clinical status of the patient. A satisfactory cushion is one that meets the patient's subjective needs, the clinician's goals, and the goals established by the expert system. If the first cushion recommended by the program proves to be unsatisfactory,

further suggestion is made based on observations and measurements made with previous cushions. Computer recommendations can be overruled at any time by the clinician as can any goals proposed by the program. Full control of the fitting process is retained by the clinician. CUSHFIT provides the structure needed to complete it efficiently.

Advantages of using this approach are numerous, including automatic documentation of observations and measurements; automatic database generation within and between collaborating centers; consistent evaluation procedures to assist with third-party payer reimbursements, and service continuity less vulnerable to specialist staff turnover. CUSHFIT has been in routine use for 2 years at Helen Hayes Hospital and is now undergoing evaluation at three other centers. Data will be shared by the collaborating centers, forming a database to study in-field performance of different cushion types and prescription practices using the program. Results will identify necessary modifications to the program following which CUSHFIT will be distributed more widely.

A Computer Interface for the TIPE Seating Pressure Evaluator

Lincoln A. Jaros, B.S.; Simon P. Levine, Ph.D.; Ronald L. Kett, M.S.

Rehabilitation Engineering Division, Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center, Ann Arbor, MI 48109

Sponsor: Rehabilitation Engineering Division, Department of Physical Medicine and Rehabilitation, University of Michigan

Purpose—Pressure sores are a major problem for individuals who are wheelchair-dependent, particularly those with sensory losses. Many researchers have investigated the causes of these pressure sores and have sought methods of preventing them. A project at the University of Michigan is investigating the use of electrical muscle stimulation as a means of preventing pressure sores (see Electrical Muscle Stimulation for the Prevention of Pressure Sores: 1 and 2). Part of this research involves measuring and recording the dynamic forces exerted at the seating interface.

The pressure transducer system being used is the Texas Interface Pressure Evaluator

(TIPE) pad. The pad consists of a 12 x 12 array of switches within an inflatable pad. Wherever the interface pressure exceeds pad pressure the corresponding switch is activated (closed). The TIPE pad is normally connected to a separate display unit which produces a transient visual picture of the pad switch conditions.

No provision for permanent recording of observed data is provided. Many experiments require information about pressure behavior to be recorded over an extended period. This recorded data must also be converted to a form which prepares it for computer analysis. An interface has been developed to meet these needs.

Progress—The electronic interface was constructed to replace the TIPE display unit and to act as a direct link between the TIPE sensor pad and a computer. The interface converts the state of pad switches to a digital format that can be read and recorded by any general-purpose microcomputer. The digitization and transmission of all switches occurs 30 times per second.

The interface is based on a Hitachi HD6803 microcomputer unit. This is a single-chip microcomputer that includes 128 bytes of random access memory, a programmable timer, a serial communication interface, and 13 programmable input/output lines in one 40-pin package. A special algorithm has been developed for switch matrix decoding to prevent false positive switch closure detection.

The TIPE pad and interface are connected to the main serial port of a Zenith Z-150 computer. The Zenith is both software and hard-

ware compatible with the IBM PC. Data acquisition software written for the Zenith receives switch matrix sample sets from the interface and stores them for later analysis. Information can be recorded at rates from 0.01 to 30 samples per second. Parameters such as sampling rate and duration are defined by the experimenter using a configuration file. This is a text file that can be edited to easily accommodate changes in experimental design.

During sampling the computer continuously updates a console screen display. This display includes time information in numeric form, pad pressure (from a pressure transducer connected through an analog/digital converter), and a 12 x 12 array of ¼-inch squares that mimic the condition of each switch (on=red and off=blue). All data can be stored on floppy disk for offline analysis. Data can be replayed over a range of speeds from ⅓ to five times real time.

Seating Systems for Body Support and Prevention of Tissue Trauma

Inder Perakash, M.D. and Hugh O'Neill, B.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Pressure sores continue to be a problem for individuals with spinal cord injuries (SCI) due to long periods of unrelieved sitting in inadequately designed wheelchairs. In addition, neurologically impaired trunk and hip musculature results in decreased trunk stability and an increased tendency to develop spinal deformities. Certain spinal deformities, such as lateral scoliosis, can increase an individual's risk of developing pressure sores by forcing one area of the buttocks to bear a greater than normal percentage of the weight. However, although most patients are aware of the need to prevent pressure sores, their primary concern is maximizing their trunk stability to enable them to be as functional as possible.

This project has two primary goals to approach the overall problem: 1) to design a universal seat cushion that will be usable by a large percentage of the SCI patient population; and 2) to determine how various sitting pos-

tures affect the distribution of pressure beneath the buttocks, and the extent to which these postures enhance or compromise trunk stability. This information will permit the development of seat cushions and other components that together promote a stable, symmetric sitting posture and help to control the magnitude and distribution of pressure beneath the buttocks.

The primary benefit to be derived from this investigation is a reduction in the incidence of pressure sores among the VA SCI population.

It has been shown by other investigators that certain areas of the buttocks are better able to tolerate pressure without developing a pressure sore than are other areas. A number of seat cushion designs have therefore been developed to transfer the load away from the more susceptible areas and redistribute it to the more tolerant weightbearing areas. Most of these cushions required custom fitting for each individual. A primary goal of this project has

therefore been to develop a seat cushion and other postural support components that could be commercially produced and would be usable by most of the SCI population without the need for custom modifications.

Progress—A cushion was designed based upon measurements taken from plaster casts of the buttocks of VA SCI patients bent over a table in a simulated seating position. The resulting design consisted of a contoured cushion of several materials, including an imbedded polyethylene stiffener under the trochanters. This design underwent eight revisions, taking into account resulting measured pressures at the ischial tuberosities, before clinical trials were conducted on more than 80 patients. The results showed the cushion to be effective in reducing interface pressures to levels well tolerated by over 79 percent of the subjects tested.

The effect of various postures on the magnitude and distribution of pressures beneath the buttocks is being investigated with subjects drawn from the inpatient and outpatient populations of the VA Medical Center Spinal Cord Injury Center. Pressure is measured at the buttocks-to-cushion interface while the subject is seated in his typical posture. Various positioning devices are then utilized to support the posture under study, and new pressure measure-

ments are taken. Subjects are also given a questionnaire on subjective factors such as perception of trunk stability and comfort.

The seat cushion discussed above has been completed and is now being marketed commercially as the Veterans Administration Seating Interface Orthosis (VASIO).

Preliminary Results—Initial tests on the effect of a 2-inch-thick foam lumbar cushion on buttocks-to-cushion interface pressure distribution have been completed. Forty subjects were selected who did not have any fixed spinal deformities and who exhibited asymmetric sitting posture. When using the lumbar cushion, 27 of the subjects (68 percent) revealed a change in pressure beneath the ischial tuberosity of greater than 5 mmHg (mean, 12.2 mmHg). Four of the subjects showed an increase in pressure, and 23 showed a decrease in pressure. Data are being gathered on the subjective responses to short- and long-term use of the lumbar cushion relative to comfort, trunk stability, upper extremity function, and overall desirability.

Future Plans—The next phase is to investigate the effect of posture on respiratory function and to refine the specifications for the lumbar pad relative to size, shape, and materials.

Seating Systems Analysis

William V. James, F.R.C.S.; John F. Orr, Ph.D.; Carson Harte, Dip.P/O

Musgrave Park Hospital, Belfast BT9 7JB, Northern Ireland

Sponsor: *Northern Ireland Rehabilitation Engineering Centre*

Progress—The researchers at the seating clinic have been aware of the wide variety of solutions for seating problems, and the difficulties of matching these to the disability. A survey is being undertaken of the clinical problems, and monitoring the effects of the solutions. Solu-

tions are being analyzed in terms of suitability and cost-effectiveness.

There is a problem in simply recording the disability. We plan to provide information on how to match seating solutions to the disabilities of wheelchair users.

Wheelchair Control and Robot Arm/Worktable Systems for High Spinal Cord Injured Persons

W. Seamone, B.A.E. and G. Schmeisser, M.D.

Johns Hopkins University, Applied Physics Laboratory, Laurel, MD 20707

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The goal of this continuing research is to complete the basic development of a working model of the robotic arm/worktable system to permit manufacturing of a limited number of units at low cost so that they may be placed in selected VA Spinal Cord Injury Centers.

Progress—In order to obtain realistic data on quadriplegic users, the latest upgraded JHU/APL system was delivered to the VA Medical Center in Hines, Illinois, in August 1985. Selected quadriplegic patients have been evaluating the system to determine the usefulness of this system for tasks such as self-feeding, reading, using a phone, and performing other tasks of daily living. Such evaluation is very useful to provide information on patients who would best benefit from the system and to develop procedures for usage of the system.

These tests are proceeding. The workstation has been designed with the specific goal of meeting total task accomplishments in complete safety and with little or no attendant assistance. The system, totally operable by the user from his wheelchair, is an integrated system that considers some of the important needs of a high spinal cord injured patient. APL's role during the past year has been primarily that of performing design modifications on these experimental systems in response to recommendations received from the Hines VAMC or previously from VA centers in Richmond, Virginia, and Cleveland, Ohio. This report summarizes some of the major equipment modifications made during the reporting period.

Multi-Axis Robot Controller: The robot arm is a six-degree-of-freedom, computer-controlled anthropomorphic limb. The individual degree of freedom may (if the user so selects) be directly controlled by selection of the desired joint to be moved. Alternatively, the user may select pre-

programmed motions to perform a task where such structured trajectories can accomplish the task. During 1984, a new microprocessor—a 6809, was chosen and integrated into the robot arm controller to increase operational reliability and flexibility. The unit can now control up to three axes of motion simultaneously in a non-coordinated fashion, resulting in reduced time to perform certain work functions. This development is now completed and all three APL units, including the model at Hines, have been updated. Instructions have been provided to the evaluators to make use of the expanded programming capability.

Interface Devices: Previous models of the workstation utilized a dual-purpose input controller mounted on the wheelchair, which can either control the wheelchair or the robot arm. This design worked well for certain patients who could utilize an E&J wheelchair compatible with this controller, but the concept lacked flexibility for patients with other models of wheelchairs. A new table-mounted chin-controller was subsequently developed, which provides an alternative to the APL-developed chin-operated wheelchair controller. One unit was delivered to the Hines VAMC and is currently being evaluated. This alternative allows the user to select the best input approach for his specific needs.

An important task on the workstation is the use of a personal computer. The user may choose between a mouthstick input system or a chin-operated Morse code keyer. Earlier workstation designs used a separate controller for robot control and a different mechanism for inputting Morse code for use on a personal computer. Such an arrangement causes undue clutter in front of the user's face. To overcome this problem, the Morse code keyer was integrated into the chin-controller, and the robot arm program selection mode was modified to allow a

single mechanical device in front of the user's face on the worktable. Preliminary testing in the laboratory indicates this system shows great promise of performing both functions and minimizes the equipment in front of the user's face.

One of the important needs of quadriplegics is the means to perform, with minimum attendant assistance, certain personal or hygiene functions. The function of tooth brushing is currently being addressed. To accomplish this function, wrist motion capability is being modified to allow 180-degree rotation. It is expected that preprogrammed modes coupled with this extended geometry capability will allow this

function to be accomplished with minimum user effort.

Manufacturing and Producibility: The APL robot arm worktable system was selected by the VA for transition to a manufacturing prototype model. Such a model has been designed and constructed, and is undergoing acceptance evaluation testing. APL has provided assistance to the manufacturer in technical problems and in the checkout procedure. Upon completion of these tests, it is expected that a small number of units will be ordered and placed in VA Medical Centers for long-term utilization by quadriplegic patients.

Wheelchairs: On-Line Measurement and Storage of the Load During a Field Trial _____

C. H. M. Boosfield, Dipl. Ing. and U. Boenick, Prof. Dr. Ing.

Department of Biomedical Engineering, Technical University of Berlin (West), D-1000 Berlin 10, West Germany

Sponsor: *Ortopedia GmbH/Kiel, E&J/Camarillo, CA*

Purpose—Fatigue-life predictions, lightweight designs, and the determination of relevant test criteria for hand-driven wheelchairs have led to this industry-sponsored project. The purpose of the investigation is to acquire extensive information about the wheelchair user's behavior, including the frequency and manner of its use, and the kind and amount of load exerted upon the wheelchair in daily use. A group of about 20 wheelchair-dependent subjects will be observed continuously for 7 to 10 days.

Progress—The entire measuring apparatus is composed of a sensor-equipped handrim wheelchair, a portable (CMOS) microprocessor-controlled measuring and storage device, and a PC/plotter unit for evaluation of the data.

The electrical signals evoked by the strain-gauge sensors in the front and rear right axle of the wheelchair (assuming a load distribution not significantly deviant from symmetrical) are in some way proportional to the three Carte-

sian forces (F_x , F_y , F_z) at the touching points between wheels and ground. Fed into the microprocessor, they are explicitly calculated and then for the reason of data condensation stored in a load-time history using a modified peak-to-peak counting method.

To regain a certain time correlation of the occurrences, the histograms are built up in a two-dimensional form. For example, the F_x -peak value in the front is stored with the simultaneous F_x -value in the rear, thus creating a stored pair.

Comprehensive analog experiments are carried out in the moment to better understand and interpret the future "time-missing" frequency distributions, whereby emphasis is laid on the phase among the measured values.

Laboratory work was accomplished by July 1986, with field trials from August through October, then evaluation. The project's deadline is March 1987.

A New Wheelchair Bumper

Michael O'Riain, Ph.D.

Royal Ottawa Regional Rehabilitation Centre, Ottawa, Ontario K1H 8M2 Canada

Sponsor: Royal Ottawa Hospital

Purpose—The purpose of this project is to redesign our wheelchair bumper so that it can be made available at a considerably reduced cost. The new bumper provides the same protection and performs the same functions as the original bumper.

Progress—The new bumper is made from plastic ABS tubing. It is attached to the wheelchair footrests by two metal connectors especially made for this purpose. If the bumper is to be used for competitive sports involving other wheelchair users also with bumpers, we recommend that it be equipped with overrides made by inserting two wooden dowels in the ABS

tubing. These overrides will prevent one bumper riding over another bumper in a head-on collision.

The only feature absent in the new bumper, which was present in the original unit, is the ability to adjust for any distance between the footrests. With the new bumper, the distance between the centers of the two rubber tips of the footrests must be determined, or specified, prior to its construction.

The bumper protects the feet of users during accidental collisions in activities of daily living and in sports. It also protects furniture from being scraped by the metal wheelchair footrests.

Bicycle-Type Brakes for Wheelchairs

Michael O'Riain, Ph.D.

Royal Ottawa Regional Rehabilitation Centre, Ottawa, Ontario K1H 8M2 Canada

Sponsor: Royal Ottawa Hospital

Purpose—The purpose of this project is to design a new braking system which can be used to slow down a moving wheelchair and control its direction. Conventional wheelchair brakes are not useful for this purpose since their function is just to lock the wheels.

The two brakes are independently controlled by levers placed behind the arm rest. Independent control enables the user to steer the wheelchair and vary the speed by applying appropriate pressures to the left and right brake levers. The brakes are adapted from standard

bicycle brakes by adding special mounts and control handles.

The benefits of these new wheelchair brakes include: 1) Daily Use—Wheelchair users finding themselves rolling down an incline and who wish to slow down or stop the wheelchair, can use the bicycle-type brakes rather than their hands. This greatly improves the effectiveness and safety of wheelchair braking; 2) Involvement in Wheelchair Sports—proper speed control is essential to many wheelchair sports, including track racing, basketball, etc.

Bioengineering Research and Development at IMA: Rehabilitation Engineering. Economic Cushion Seat of Variable Configuration for Cerebral Palsy Children

L. C. Nava and P. A. A. Laura, Ph.D.

Instituto de Mecánica Aplicada (CONICET) Instituto Naval Puerto Belgrano, 8111 Argentina

Sponsor: Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina

Purpose—The fundamental design parameters of the cushion seat of variable configuration for

cerebral palsy children are: 1) low cost; 2) usability by a large population of disabled children;

3) simplicity in construction so that it may be fabricated by disabled workers or even members of the family of the children affected by cerebral palsy; and 4) versatility of the system so that it allows for manual transportation of the disabled child. It is also attachable to an automobile seat and can be mounted on a

standard wheelchair.

The cushion seat is fabricated with materials easily available in a developing country. High ductility aluminum plate, polyurethane foam, and a non-toxic paint is applied in several coatings.

Mini Litters: A Specialized Mobility Construction for Spinal Cord Injured Patients with Bilateral Lower Limb Amputations and Diminished Seating Capacity

James W. Barnes, AA, BBA, CO and Herman Taylor
Orthotics Laboratory, US Veterans Hospital, Memphis, TN 38104
Sponsor: VA Rehabilitation Research and Development Service

Purpose—The spinal cord injured patient has many problems inherent in and associated with his/her acquired disability. One of the problems is a diminished circulatory function and associated absence of skin sensitivity below the spinal cord level of injury. This frequently results in superficial skin and deep tissue ulcers, primarily over ischial tuberosities and over the femoral heads through pressure due to immobility while being confined to bed, trauma secondary to transferring, or shear forces during sitting or ambulation in mobility systems, wheelchairs, or litters. If these ulcers are severe, conditions often develop necessitating the amputation of the affected limb or limbs.

SCI patients having bilateral above-knee amputations, bilateral hip disarticulations, or a combination of the two types, pose a challenging problem concerning their daily ambulation in a home, institutional, or medical environment. After such amputations, sitting capacity is severely reduced or eliminated completely as a direct result of the majority of pressure-bearing areas required for sitting having been removed by the amputation. Where previously the posterior thigh had borne weight, now the residual limb simply flexes when the patient sits, leaving the ischial tuberosities and the sacrococcygeal area to bear the total body weight. This also results in a change in center of gravity of the wheelchair-bound patient and affects the force vectors of posteriorly directed shear forces.

The therapeutic value of independent mo-

bility can reduce the hospital stay of a patient with these problems, which results in financial savings to the patient or public facility while freeing bed space for other patients.

Progress—The Orthotics and Prosthetics Laboratory at the Veterans Hospital in Memphis, in dealing with this problem, has created a device that is simplistic in design yet functional in operation. Originating from the idea of the manually propelled full-sized litter, a manual and electric-powered short litter was designed from a standard manual or motorized wheelchair frame. This accomplishes several purposes. The mini litter is not cost prohibitive; it is safe to operate at home and in a controlled institutional environment; it is suitable for indoor and outdoor use; it is transportable and will collapse like a regular wheelchair for shipment; it increases the patient's mobility and creates a greater degree of independence.

The type of wheelchair used for the manual powered mini litter was an Everest & Jennings Premier Model with amputee frame, reclining back, full-length arms, 20 x 2.125 pneumatic tires for comfort and traction, and 8" x 1" hard rubber front tires for ease of turning and proper torso angulation. Standard armrests were chosen over adjustable height armrest for strength and stability in removing and attaching the mattress frame.

Design and fabrication of such a vehicle focused on three concerns. First, safety considerations were paramount with regard to changes

in the center of gravity of a high level SCI patient with bilateral above-knee amputation and the propensity of a vehicle such as this to tip over forwards and backwards while being operated. Second, the vehicle had to be easily mounted and dismounted by the patient, be comfortable, and provide for maximum use by the patient. For this, many factors were considered, such as the eye level of the patient during vehicle operation, the ability and the range of motion of the upper extremities of the patient to propel a selection of available wheels, and the respective individual motivation level of each patient. Third, practical considerations in fabrication included initial cost, future repairs, maintenance cost, parts accessibility, and access to repair centers.

Modifications and changes to this chair consisted of attaching two sets of amputee adaptors on the existing offset wheels to lengthen the wheel base. The upholstery was completely removed. Anti-tipping devices were installed on the rear posts and two 6-pound counterweights were placed for more effective stabilization. Measurements were taken of the patient from axilla to the end of the torso to determine necessary length of the mattress frame that would position the patient's shoulders directly over the drive wheels for proper excursion to achieve maximum results for energy/effort expended. When associated with the length and weight of the patient, this helps determine the length of the wheel base and the center of gravity of the vehicle. It enabled us to relate the two within safety limits for the propulsion. In addition to length determination, we also decided to increase the safety aspect by ensuring that the alignment of the frame would be on a descending angle from the head of the

patient to the rear of the vehicle or from the large drive wheels to the smaller directional wheels. The center of gravity was moved even further, which immensely decreased the possibility of the vehicle turning over as a result of a sudden stop or hard bump on an irregular surface.

Once the size of the mattress frame was determined, its length, width, and height were fabricated from $\frac{1}{2}$ " plywood and lined with naugahyde. Metal reinforcements were added for safety and structural stability. A second frame was formed from lightweight aluminum conduit and formed in such a way as to be attached to the plywood mattress frame and to be attached also to the full length non-adjustable armrests of the chair. The frames were attached to the armrests with bolts and nuts. The armrests were then welded with a crossbrace consisting of $\frac{1}{2}$ " steel flat bar stock to make the two armrests one removable unit. The mattress, a 4" thick 65-percent density foam rubber covered in washable naugahyde, was then added to the frame. Measurements were taken to determine the length of the wheel lock extensions which were fabricated and attached. A safety belt was attached along with a luggage tray and utility pouches.

An Everest & Jennings 3P motorized chair was also adapted and with the additional weight of batteries and the different design of the motorized frame, the only modifications required were the wheel lock extensions, anti-tipping devices and attaching the hand control to the mattress frame.

These carts are not designed for primary vehicles. They are used as a secondary vehicle to allow time off pressure-affected areas of the body.

H. Personal Licensed Vehicles

Unistik Vehicle Controller: Reliability, Applications, and Secondary Controls

Catherine W. Britell and Dale R. Johnson, P.E.

Spinal Cord Injury Service, Veterans Administration Medical Center, Seattle, WA 98108

Sponsor: VA Rehabilitation Research and Development Service

Progress—The Unistik Vehicle Controller (UVC) has been developed under a joint inter-agency agreement by the National Aeronautics and Space Administration (NASA) and the Veterans Administration (VA) for the purpose of providing a means for enabling severely handicapped individuals to drive a motor vehicle. Work to date has included development of primary (acceleration, steering, braking) controls and installation in a 1981 Ford van, conversion to a programmable microprocessor-based feedback system, and development of simple electromechanical secondary controls. The device consists of the following components:

Driver Interface: This includes a high-resolution, low-effort joystick that may be modified to be used with or without orthoses. The control box and forearm support are brought into proper position for the driver by an electric positioning mechanism. The joystick controls acceleration, steering, and braking. Gear selection and starter switches are situated on the primary control box and may be operated with pushbuttons or toggles. A high brake bias is incorporated into the joystick mechanism, which maintains braking when the hand is moved to change gears. The parking brake is also set by joystick position.

Signal Controller: This is an analog electronic system that processes signals from the driver interface, integrating and modifying them according to feedback from tachometer signals and other variables. Steering control uses a high-gain mode for maneuvers at slow speed, and a low-gain mode to enable the system to operate smoothly at highway speeds. The signal controller may be modified in various ways according to the needs of the individual driver.

Vehicle Interface: The actuators are servomotors that can very rapidly provide the necessary force to move conventional high-effort driving controls. All vital functions have redundant actuation, which automatically becomes functional in the event of failure of any of the primary actuators. Modification of the vehicle electrical system was carried out, and backup batteries were added in order to provide constant, reliable power to the signal controller and actuators. Servos were chosen to maintain function well within operating limits, and temperature control was carefully addressed.

Microprocessor-Based Monitoring System: This provides vehicle security, a self-diagnostic startup system, and continuous monitoring of control function, activating redundant systems and alerting the driver in case of malfunction. The monitoring system cues the driver in the startup sequence and will not allow the engine to be started unless the correct driver access code is entered and the vehicle control system is demonstrated to be functioning properly.

Secondary Control System: An electromechanical secondary control system has been developed that localizes parallel secondary controls (horn, lights, wipers, CB radio, turn signals, hazard lights) and some sequential functions (automatic wheelchair tiedown, parking brake release) in a second movable control box that may be located in any position convenient to the driver. Operation of this secondary control system requires a second functional extremity at present.

The Unistik is presently undergoing exhaustive component life-cycle and system safety and reliability testing, as well as extensive clinical evaluation to better define target population and training requirements. Preliminary

evaluation suggests that quadriplegic drivers at the C5 level and triplics can safely and effectively operate the system. Ongoing plans include development and adaptation of a voice-actuated secondary control system, using NASA technology that is already available and well-developed in this area.

The Unistik represents a unique, cost-effective, and reliable system for enabling individuals with severe physical disabilities to drive a motor vehicle. It is wholly contained within the

passenger compartment, is easily installed, and retains the integrity of the normal vehicle control system. Since the device is a 'bolt-on' system, it can be moved to a new vehicle with ease and is expected to last the lifetime of the user. The expected relative low cost and wide availability of the system will make driving available to a significant number of disabled people who would otherwise be dependent on public transportation.

I. Functional Electrical Stimulation

1. General

EMG as Force-Feedback in Closed-Loop Functional Electrical Stimulation

Carl P. Mason, M.S. and John A. Gruner, Ph.D.

New York University Medical Center, New York, NY 10016

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to develop a closed-loop functional neuromuscular stimulation (FNS) system to improve dynamic force and position control of paralyzed limbs. If stimulation systems can be made more functional, they should receive greater acceptance.

The cat ankle joint, including the gastrocnemius and tibialis anterior muscles, serves as the model for developing closed-loop FNS control. The gastrocnemius muscle is electrically stimulated by intramuscular (IM) and nerve cuff (NC) electrodes while the force (F) and stimulated motor unit responses (SMUR) are recorded in order to determine the relationship between these variables and stimulation (S) parameters, electrode configurations, and muscle length. Variable amplitude, biphasic bipolar rectangular 100 microsecond stimulus pulses with a 5-second interpulse interval were used.

Preliminary Results—In intramuscular stimulation (IMS), muscle tension as a function of stimulus amplitude follows a monotonic curve

(as expected). However, IMS was sometimes found to be highly nonlinear, exhibiting a plateau, possibly due to recruitment of a distant nerve branch within the muscle. Using decreasing versus increasing amplitude pulse series had little effect on the tension versus pulse amplitude (PA), whereas reversing the polarity of the bipolar IM electrodes shifted the curve (i.e., response threshold) significantly without changing the shape.

Bipolar nerve cuff stimulation (NCS) generally resulted in monotonic tension curves similar in shape to IMS curves. However, changing electrode polarity of the NCS electrodes in some cases changed the shape of the curve as well as shifting it, introducing an intermediate plateau. Stimulus thresholds for NCS were between 0.2 and 0.6 ma versus 1 to 5 ma for IMS. F versus PA curves at several lengths under NCS showed increasing tension with length. $\Delta\text{force}/\Delta\text{PA}$ increased with length, particularly at mid-range values. The SMUR peak-to-peak amplitudes were independent of muscle length.

At all lengths, force was monotonically related to SMUR. These F versus PA curves can be described with a third-order polynomial with a correlation coefficient $r^2 \approx 0.99$.

The relationship between force and SMUR is sensitive to the location of the EMG electrodes. Monotonic curves were most often obtained with electrodes spaced <5 mm apart and axial with the muscle fibers. We have found that 1) increasing versus decreasing pulse amplitude series generate nearly identical forces; 2) comparison of F versus SMUR curves resulting from IMS at sites several millimeters apart were similar in shape only; 3) SMUR is consistently saturating before force saturated; and 4) the correlation between peak-to-peak SMUR and F or PA was better than for integrated SMUR versus F or PA.

With increasing electrode separation (especially >1 cm) and/or orientations perpendicu-

lar to the muscle fibers, F versus SMUR curves were often nonmonotonic. The nonmonotonicity in these curves originates in the SMUR responses. When electrodes were widely separated, the probability of recruiting different motor units with much different thresholds increases, resulting in polarity reversal as first one and then another motor unit is recruited.

The force produced by IMS and NCS depends both on electrode location and stimulus polarity. There is little evidence of hysteresis with increasing versus decreasing stimulus series. The relationship between peak-to-peak SMUR and peak tension was often quite linear when electrodes were positioned axially and close together, but SMUR were not found to be affected by length, limiting their use as a force-feedback signal primarily to onset of tension and saturation.

Implantable Systems for Stimulation of Skeletal Muscle

P. Hunter Peckham, Ph.D. and Michael W. Keith, M.D.
Case Western-Reserve University, Cleveland, OH 44109

Sponsor: *National Institutes of Health*

Purpose—The object of this project is to develop and evaluate, in animals, an implantable stimulator for electrical excitation of paralyzed muscle. The implant is an 8-channel externally powered and controlled device.

Progress—Progress on implantable stimulators has been made in three areas: circuitry development, packaging, and evaluation. Circuitry development has focused on modification and reintegration of the CMOS semi-custom integrated circuit. The circuit has been redesigned to provide external amplitude regulation, as well as pulse width and interpulse interval control available in the present implant circuitry. The design provides 5-bit amplitude regulation over 0-20 ma, 8-bit pulse width regulation over 0-255 microseconds, and 1 millisecond interpulse interval regulation over 0-50 Hz for each of eight channels. Reintegration is under way at present.

Packaging development has focused on im-

provement of packaging materials to provide a high quality device. The package utilized is a titanium with epoxy/silicone elastomer for stabilization of interface junctions between the package and the leads and antenna. Packaging protocols have been detailed to provide quality assurance throughout assembly.

Evaluation has focused on monitoring, in a dog model, the performance of the device during both passive (no stimulation) and active periods. These studies have been carried out *in vitro* and *in vivo* in four animals, each of which have been operational for more than 6 months (longest, 16 months).

Future Plans—Future studies will focus on continued *in vitro* and *in vivo* monitoring in the dog animal of the implantable stimulator and its subcomponent assemblies (i.e., electronics, package, connector, leads, electrodes). The purpose of these studies is to determine the reliability and stability of implant function and to

determine a means of analysis of system malfunction. In addition, we expect to incorporate this device in studies utilizing human subjects

in the project entitled "Functional Neuromuscular System for Upper Extremity Control," reported elsewhere in this issue.

Recruitment Properties of Nerve Cuff and Epimysial Electrodes

D. McNeal; L. Baker; J. Symons; N. Gurbani

Rancho Los Amigos Rehabilitation Engineering Center, Downey, CA 90242

Sponsor: *National Institute of Handicapped Research*

Progress—A preliminary investigation of the recruitment properties of nerve cuff and epimysial electrodes has been performed. Monopolar cuff electrodes were chronically implanted in the left posterior tibial nerve in two cats. In two other cats, cuff electrodes were implanted on the left tibial nerve and epimysial electrodes were implanted on the right lateral gastrocnemius. After 3 to 4 months, the electrode wires were explanted and the nerves stimulated to determine recruitment data at various pulse durations for all electrodes. No other stimulation was applied during the study.

Electrodes used in this study were manufactured by Avery Laboratories, Farmingdale, NY. The nerve electrode had a 1x2 mm platinum disk placed inside a 3 mm diameter silicone rubber cuff. The epimysial electrode had a 1x2 mm platinum disk placed on a 1 cm diameter sheet of silicone rubber reinforced with Dacron. During testing, a 2 cm diameter stainless steel disk was placed in the leg opposite to that being tested and was used as the ground electrode.

In the first two animals, stimulation values at threshold and maximal levels of contraction were determined by simply palpating the muscle. Histological studies of the nerves were

then performed. In the second two animals, recruitment data were collected over a wide range of pulse amplitudes and pulse durations using a monophasic waveform. The procedure followed was to fix pulse duration at 10, 20, 50, 100, 200, or 350 microseconds and then vary pulse amplitude to generate ankle plantarflexion torque in small steps between threshold and maximal values. A torque transducer built in our prototype shop was used for this purpose. To prevent excessive fatigue, only twitches were produced and the peak value of the twitch response was recorded.

It was found that thresholds for the monopolar cuff electrode were between 0.1-0.2 mA while the maximal stimulation values were approximately twice the threshold value. Pulse modulation with nerve cuff electrodes requires a step size no greater than 1 microsecond for adequate regulation of muscle force. Stimulation levels for the epimysial electrodes were 30-100 times higher than those obtained with nerve cuff electrodes. Controllability is not a problem with epimysial electrodes, but there is a high cost in energy expenditure. Additional studies are planned to yield sufficient data for statistical analysis.

Ljubljana Rehabilitation Engineering Center—Core Area: Functional Electrical Stimulation

Ruza Acimovic-Janezic, M.D.

Rehabilitation Engineering Center Ljubljana, University Rehabilitation Institute, Ljubljana, Yugoslavia

Sponsor: *National Institute of Handicapped Research*

Purpose—In functional electrical stimulation (FES) of extremities, electric current is applied to neuromuscular systems of the limbs to cause

functional movement of a paralyzed extremity. Electronic stimulators have functional and therapeutic properties that cannot be attained

by any other orthosis. The development of such FES systems is the primary goal of the Ljubljana Rehabilitation Engineering Center, which is made up of the following institutions: the University Rehabilitation Institute, Faculty of Electrical Engineering, J. Stefan Institute, and University Medical Center.

Progress—During the past 3 years (1983-1985), FES research was divided into five areas. The following were the major achievements.

1) *Enhancement of applicability of FES devices and therapies for paretic patients* (Uros Stanic, D.Sc., Dipl.Eng., J. Stefan Institute). A dual-channel stimulator for gait correction in paretic patients was developed. A multichannel EMG recording system was introduced and neuromuscular control of gait studied. Design of 3-channel implantable stimulators was also begun.

2) *FES of spinal cord injured patients* (Alojz Kralj, D.Sc., Dipl.Eng., Edvard Kardelj University Ljubljana). A posture-switching technique prolonging standing time was introduced. Stair climbing by a completely paralyzed person was achieved. Percutaneous femoral stimulation and flexor reflex triggering with an implant was started.

3) *Electrotherapy of spastic and paretic extremities* (Lojze Vodovnik, D.Sc., Dipl.Eng.,

Edvard Kardelj University Ljubljana). Various therapeutic approaches (passive joint ranging, cooling, afferent nerve stimulation, TENS, epidural stimulation) were examined together with optimization of stimulation parameters and sites for treatment of spasticity.

4) *Microcomputer-aided diagnosis and rehabilitation of the neurogenic bladder using electrical stimulation* (Peter Suhel, D.Sc., Dipl.Eng., Edvard Kardelj University Ljubljana). In this connection, FES treatment of urinary incontinence in elderly women was started, and a microcomputer-controlled catheter puller was developed to assist in treatment.

5) *Quantification of effects of electrical stimulation in patients with urinary disorders* (Stanislav Plevnik, D.Sc., Dipl.Eng., Edvard Kardelj University Ljubljana). An intensive electrical stimulator for everyday short-term self-stimulation at home was developed together with an electrical fluid bridge-testing device.

The researchers of the Ljubljana Rehabilitation Engineering Center have been invited speakers at international meetings and conferences and have published in scientific journals. The stimulators are manufactured by two Yugoslav factories, and patients from all over the world are coming to the University Rehabilitation Institute because of the unique FES rehabilitation approach.

Implantable Multichannel Implant Systems

D. McNeal and R. Waters

Rancho Los Amigos Rehabilitation Engineering Center, Downey, CA 90242

Sponsor: National Institute of Handicapped Research

Progress—A comprehensive R&D program for the development and application of implantable multichannel stimulation units and associated hardware is in progress. Our immediate clinical objectives are 1) gait enhancement in patients with unilateral impairment, and 2) long-term therapeutic exercise for patients with bilateral involvement. The status of several projects within this program are described below.

Clinical Laboratory for FES Research (P. Meadows, D. Kannenberg, J. Campbell, N. Su). A clinical laboratory is being developed to sup-

port research with an implantable stimulation system. The laboratory will house all of the equipment and personnel required to train implant candidates before and after surgical implantation as well as to determine stimulation patterns used by an external controller to control the implant devices in all modes of operation. The laboratory equipment directly involved with the implant operation can be divided into three categories: the laboratory computer system, the gait walkway, and the implant/external controller/physical therapist control-

ler system.

Laboratory Computer. Before an experimental run, a computer will be used to formulate control sequences for each of 16 possible channels and to transfer stimulation data table information to/from the external controller. During the run, the computer will collect goniometric, electromyographic, and force data from the patient as he/she proceeds along the gait walkway. These data will then be analyzed and results presented to the clinicians using the laboratory. In this way, parameters for gait stimulation may be quickly determined and analyzed for modification by the clinicians.

To present the results of data analysis in an easily interpreted manner, and to facilitate the modification of data tables corresponding to gait stimulation parameters, a high-speed, high-resolution, color graphics workstation will be used. Data table information that corresponds to pulse widths for individual pulses within a channel sequence may be quickly reviewed and modified using a mouse and sent back to the laboratory computer for processing and transmission to the external controller.

Gait Walkway. The gait walkway will be approximately 8 m long and will have color video recording equipment and a gait stride analyzer available for patient performance measurement. Force measurements will be available from instrumented shoes and canes.

Implantable Stimulator. The implantable stimulator utilizes a 3-chip set of integrated circuits developed at Stanford University Integrated Circuits Laboratory. The chips and their associated electronics are enclosed inside a titanium, hermetically sealed can, with tantalum feedthroughs for eight electrode and three antenna connections. The implantable stimulator receives its information and power from a 20-MHz transmitter modulated with an external timing control code, composed of two words, a "Transition" word, and an "Amplitude" word. The Transition word is used to change the state of any of the eight channels. The Amplitude word selects the current amplitude of the state sequence of a given channel. It has three bits to individually address the eight channels, four bits to adjust the current magnitude, plus one

more bit to set the current polarity.

The implant is approximately 1.75 inches in diameter and 0.375 inches thick. Protruding from the edge of the package are connectors. Attached to these connectors are up to eight electrode leads, terminating in monopolar nerve cuff electrodes. The implant will be placed over each device.

The implant delivers variable pulse width biphasic pulses, with amplitudes from 200 microamperes to 2.25 microamperes. Pulse width control spans the range from 26 to 300 microseconds with a step size of 156 nanoseconds.

External Controller. Supplying information and power to the implant units is a microprocessor-based external controller worn on the patient's belt. The controller uses a CMOS microprocessor for low-power portable operation, and contains circuitry needed to convert stimulation parameter information into the control words and then to implement the transmission process.

The controller has sufficient memory to contain pulse information for 16 channels in several modes of operation in the form of data tables. The elements of these tables correspond directly to the pulse widths required for a particular muscle group to produce a desired amount of force. In this manner, a modulated sequence of muscle forces may be defined to realize the desired trajectory of the patient's lower extremities. The controller device is able to control two implant stimulators for a total of 16 channels.

Therapist Control Unit. Communicating to the external controller worn by the patient will be a therapist control unit. This device is carried by the physical therapist or another clinician walking with the patient during gait runs. With this device, the therapist is able to locally adjust scale factors for any of the channels of the implanted stimulators, to interrogate the status of the implant system, to trigger or modify the operation of the external controller, and to generally assist the external controller in implant system operation. The device has a two-line, 16-character alphanumeric liquid crystal display and a number of controls that allow extensive interaction between the therapist and

the implant/controller system.

Neuroaugmentive Procedures for Modification of Abnormal Motor Control in Patients with Spinal Cord Injury

M. R. Dimitrijevic, M.D., A. M. Sherwood, P.E., Ph.D.; R. J. Campos, M.D.; P. C. Sharkey, M.D.
Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *National Institute of Handicapped Research*

Progress—Sixty patients with muscle hypertonia after spinal cord injury have undergone spinal cord stimulation (SCS). These patients had spinal cord injuries ranging from C2 to T12. Electrodes were placed above, below, or above and below the lesion in the posterior epidural space for a period of at least 3 days during which time stimulation pulses, typically of 3 to 5 mA amplitude and of 0.2-millisecond duration at 30 Hz were applied. The effects of spinal cord stimulation were monitored by recording motor unit activity with surface electrodes over leg muscles during an examination of segmental and suprasegmental spinal cord activity, in addition to patient reports and neurological evaluations.

Preliminary Results—The results of SCS can be divided into four distinct categories. In Group I, consisting of 17 patients or 28 percent of the entire group, the effect was characterized by marked suppression of muscle hypertonia and so-called spontaneous spasms. In Group II, the effect of spinal cord stimulation on muscle hypertonia was moderate as evidenced by the suppression of the tonic but not phasic features of spasticity. This was observed in 20 patients,

or 33 percent of the total. In Group III, neurological and neurophysiological evaluations revealed only a marginal effect. The condition of this group of nine patients (15 percent) did not improve significantly. In Group IV, consisting of 14 patients (23 percent), there was no effect.

SCS was markedly or moderately effective in reducing spasticity in 63 percent of the patients. We found that control of spasticity by SCS was not correlated with the severity of spasticity, the type of spasticity (flexor or extensor), or the ability to ambulate. However, stimulation in incomplete cervical lesion patients was 90 percent effective, compared to 14 percent effectiveness in complete cervical lesions, and stimulation below the lesion was more effective than above. We concluded that SCS is effective when electrodes are properly positioned below the lesion over the posterior aspect of the spinal cord in patients with some residual spinal cord function. We hypothesize that SCS controls spasticity by modification of activity of the spinal-brainstem-spinal loop and also by suppression of segmental excitation through antidromic activation the of proprio-spinal pathways.

Evaluation of the Effectiveness of Electrical Stimulation of the Leg Muscle in Cerebral-Palsied Patients

M. Solomonow, Ph.D. ; M. Laborde, M.D. ; H. Soboloff, M.D.
Louisiana Center for Cerebral Palsy, Touro Infirmary, New Orleans, LA 70115

Sponsor: *United Cerebral Palsy of New Orleans*

Progress—The previous phase of the project clearly indicated that FES of the quadriceps muscles of cerebral-palsied patients substantially increased muscle bulk, tone, strength, and endurance. The evaluation, performed on the

Cybex II system, had large standard deviations when the statistical analysis was performed due to human factors associated with patient collaboration, level of associated mental retardation, attitude, etc.

A myoelectric recording and processing system, designed to be used as a fatigue monitor during isometric knee extension loading, is simple and easy to use with this group of pa-

tients. The EMG activity at the end of 30 seconds is compared to the initial level and its ratio derived as an index for muscle progress.

Adaptive Neuromuscular Stimulator

M. Solomonow, Ph.D.; R. Baratta, M.Sc.; B-H. Zhou, E.E.

Bioengineering Laboratory, Department of Orthopaedic Surgery, Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: *LSU Bioengineering Foundation*

Purpose—Different skeletal muscles are controlled with different firing rates and recruitment control strategies. The biceps, for example, utilize motor unit recruitment to derive 80 percent of its maximal force, and firing rate increase to obtain the final 20 percent. The FDI muscle, however, utilizes recruitment to obtain its initial 35 percent of the maximal force and to obtain the remaining 65 percent by firing rate increase.

In order to restore function to paralyzed muscles using electrical stimulation with a natural physiological control strategy, a new system was designed and tested.

Preliminary Results—The system is based on computer-controlled dual-channel stimulators, one modifying the muscles' firing rate and the second its motor units recruitment range. Testing clearly showed that control of recruitment in the force range of 20 to 100 percent of the maximal force is possible with concurrent increase in firing rate. Pure firing rate is possible once the full recruitment is obtained. The system, therefore, can control any skeletal muscle according to its natural control strategy with substantial increase in force accuracy and fatigue reduction.

Fitness Improvements and Physiological Responses to FES Exercise

Roger M. Glaser, Ph.D.; A.G. Suryaprasad, M.D.; S. C. Gupta, M.D.; Steven R. Collins, M.D.; Frank J. Servedio, Ph.D.; Glen M. Davis, Ph.D.;

Wright State University and Veterans Administration Medical Center, Dayton, OH 45428

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The overall purpose of this research project is to develop exercise techniques, incorporating functional electrical stimulation (FES) of paretic or paralyzed skeletal muscles, to improve muscle strength and endurance, as well as cardiopulmonary fitness of patients with spinal cord injury or other neuromuscular dysfunctions. The goals of this project are to evaluate the effectiveness of protocols that use: 1) only FES exercise of paralyzed muscles; 2) simultaneous combinations of FES-induced leg exercise and voluntary arm exercise; and 3) simultaneous combinations of voluntary and FES-induced contractions of the same paretic muscles.

Progress—To accomplish these studies, specialized instrumentation have been designed and constructed including: closed-loop and open-loop stimulator systems utilizing either digital or analog circuitry; FES knee extension exercise devices; and arm ergometers (arm crank and wheelchair) for voluntary exercise.

Several studies, which have been performed, or are currently in progress, include: development of standardized FES knee extension exercise protocols to provide safe and effective means of evaluating performance, and to enhance the capacity of paralyzed muscles for this form of exercise; determination of metabolic and cardiopulmonary responses for FES exercise in comparison to these responses obtained

for the same exercise performed voluntarily by able-bodied individuals; determination of metabolic and cardiopulmonary responses for combined FES leg and voluntary arm exercise; and evaluation of central hemodynamic responses (ventricular stroke volume and cardiac output) for various forms (dynamic and static) of FES exercise.

Results—Chronic FES knee extension exercise (3 times a week for 12 weeks), using a progressive intensity load weight protocol, had resulted in marked improvements in quadriceps muscle strength and endurance. No known damage to the muscles, bones, or skin had occurred. Linear increases in oxygen uptake (VO_2) and pulmonary ventilation (VE) with exercise intensity were observed. However, heart rate (HR) did not increase above resting values. The maximal VO_2 achieved (20 lb-load) was nearly twice the rest value. These relatively low maximal VO_2 and VE values and the lack of HR response cast doubt upon the efficacy of this exercise mode to provide a cardiopulmonary training effect. FES exercise also appeared to be inefficient in comparison to voluntary exercise. This was indicated by higher VO_2 for FES exercise than for voluntary exercise (performed by able-bodied individuals) at each intensity level. The inefficiency may be due to histochemical characteristics of the paralyzed muscles, inappropriate stimulation patterns and stimulation of inappropriate muscle fibers.

One factor which probably limits FES exercise capability is inadequate blood flow to and from active muscles. It appears that cardiovascular adjustments during voluntary exercise (e.g., increased cardiac output and redistribution of blood from inactive to active skeletal muscles), which are normally mediated through autonomic sympathetic pathways, may not occur to the same extent with FES exercise. This is because FES bypasses the central nervous system by peripherally inducing contractions, and many patients with impaired neuromuscular function (e.g. spinal cord injury) also have impaired autonomic function.

In another study, spinal cord injured subjects performed maximal effort voluntary arm

crank ergometry (ACE) and FES-induced knee extension exercise separately and simultaneously. We found additive VO_2 and VE responses during the hybrid FES-ACE exercise, whereas the marked increase in HR was completely an effect of the voluntary ACE exercise. Knee extension performance, as indicated by resistance to fatigue, was significantly better during hybrid FES-ACE exercise than during FES alone. This may be due to enhanced sympathetic stimulation induced by the voluntary ACE exercise. These findings suggest that hybrid FES-ACE exercise may be used to increase active muscle mass and the maximal VO_2 achieved. This may improve the aerobic training capability of paralyzed individuals.

Preliminary results of an ongoing study suggest that simultaneous combinations of voluntary and FES-induced contractions of paretic muscle enhances training capability for strength and endurance. This form of hybrid exercise can permit significantly stronger contractions than those elicited by voluntary effort alone, and enables exercise to continue for longer periods of time. Such training may ultimately result in greater and more rapid restoration of voluntary function.

In an effort to promote blood flow in the lower extremities via FES, we performed a pilot study on able-bodied subjects. A multichannel stimulator was used to elicit appropriate pulsatile contractions of the calf and thigh muscles, and in effect create a venous muscle pump. During FES, we found significant increases in central hemodynamic responses above rest values suggesting reduced blood pooling in the legs. Applications of this "pump" may include deep venous thrombosis and decubitus ulcer prophylaxis in immobilized patients.

Future Plans—Our future research will focus on the implementation of long-term exercise training programs using advantageous FES techniques. We will also continue our physiologic evaluations to determine mechanisms for any improvements of muscular and cardiopulmonary functions, as well as to provide a better understanding of the limiting factors for FES exercise.

2. Upper Limb Applications

Sensory Augmentation for FES Upper Extremity Prostheses

Ronald R. Riso, Ph.D. and Anthony R. Ignagni
Case Western Reserve University, Cleveland, OH 44109

Sponsor: *National Institute of Handicapped Research; National Institutes of Health*

Purpose—The purpose of this project is to provide substitute and augmentative sensory feedback to enhance the utility of FES upper extremity prostheses.

Progress—An electrocutaneous communication system has been designed that provides feedback information about prehensile force, the output of the shoulder position command transducer, and stimulator status. Efforts to date in our laboratory have led to the development of a six-level frequency coding paradigm to input grasp force information to the subject. Electrical stimulation parameters have been selected that attempt to optimize signal discriminability and minimize accommodation effect. The frequency modulation grasp force information is provided by activating one or the other spatially discrete elements of a multi-element electrocutaneous display.

The particular element of the electrode array (display) that is active at any given moment provides a spatially encoded correlate of the output of the subject's shoulder position command transducer. An array that consists of five electrodes, placed on one side of the upper back skin, scales the subject's command feedback signal into five equal parts. During the past year the efficacy of this spatial position electrocutaneous feedback scheme was demonstrated by having subjects perform shoulder position tracking tasks with and without the feed-

back display turned on.

The final aspect of the composite sensory augmentation system consists of furnishing machine state information to the FES system user. A scheme to do this was developed over the past year and is now being evaluated in one quadriplegic individual. The machine state feedback includes coded electrocutaneous messages that assist the FES system user in: 1) selection of the mode of grasp; 2) specification of the position of the shoulder that corresponds to the start or "zero" point of the command signal; and 3) realignment of the shoulder before reentry into the state of voluntary active control after the system has been put into a "Lock Grasp" state. (The Lock Grasp state refers to the condition during which the user can set the muscle stimulation parameters at any arbitrary level of command and then disengage the shoulder position controller and have the FES system automatically maintain the muscle stimulation parameters at the selected level.

Future Plans—Future work will concentrate on performing functional evaluations of the composite sensory feedback system in selected quadriplegic individuals. The functional tests will be laboratory-based and consist of simulated activities of daily living as well as more abstract assessments that involve the manipulation of instrumented objects.

Implantable Sensor for Two-Degree-of-Freedom Position Transduction

P. Hunter Peckham, Ph.D. and Michael W. Keith, M.D.
Case Western Reserve University, Cleveland, OH 44109

Sponsor: *Spinal Cord Research Foundation*

Purpose—The purpose of this project is to design, develop, and evaluate an implantable device that will provide two independent (degrees-of-freedom) signals for use as command control and feedback source in upper extremity assistive systems for the high level spinal cord injured population. The implanted device will measure relative skeletal position changes of opposing bony segments. The movement will be generated by voluntary movement of the body over which the user retains voluntary control

(e.g., shoulder in C4 injury or lower, wrist in C6 or lower). This information will provide the means for the user to control his hand position and force in a functional neuromuscular stimulation (FNS) hand assist system. Alternatively, the signal may be used in a position feedback loop, such as for control of wrist position by FNS in a C5-level quadriplegic subject. It will also have application to control upper extremity prostheses and a powered wheelchair.

Functional Neuromuscular Systems for Upper Extremity Control

P. Hunter Peckham, Ph.D. ; Michael W. Keith, M.D. ; Patrick E. Crago, Ph.D.
Rehabilitation Engineering Program, Veterans Administration Medical Center, Cleveland, OH 44106

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The objectives of this project are to develop implantable systems for functional neuromuscular stimulation and to implement and evaluate their effectiveness in providing restoration of upper extremity function in the high level spinal cord injured subject. The studies performed in the past year have focused on the development of the system hardware and software for implementation of implantable stimulator systems into human subjects.

Progress—Progress in the past year has been made in both development of the implantable stimulation system and in the clinical studies. The implantable system has been completed and is ready for human implantation. The implantable system consists of the external command control sensor, the portable processor-transmitter, and the implanted stimulator. The external command controller is a two-degree-of-freedom position sensor for shoulder-sternum measurement. The sensor has been redesigned so that it now utilizes linear Hall effect devices as the sensor elements. The entire unit is cast in acrylic for ease of fabrication and greater reliability.

The external processor has also undergone redesign to provide for more versatile processing of input commands and enhanced generation of more complex stimulation sequences. The unit is based on two CMOS microprocessors (RCA CDP6805E3) and has the capacity to control up to four implantable stimulators. Software has also been enhanced to simplify programming of the stimulation and command sequences. Implantable stimulator development has focused on aspects that are central to human implementation, specifically for leads, connectors, and electrodes. A new in-line connector has been implemented and tested. A connector is essential for human implants to allow for serviceability in the event of failures. The connector is small and flexible, and thus keeps stress distributed along the lead.

The fabrication procedures of the epimy-seal electrodes have been improved to provide better adhesion between components and more secure surfaces for suturing. Implantable components have been fabricated with at least double redundancy in stimulator devices, connectors, leads, antennae, etc., to ensure that backup support and repair components are

available. All of the procedures for human implantation have been developed and all instrumentation for surgical installation have been completed.

Clinical studies have focused on development of surgical and evaluation protocols and selection and preparation of human subjects. The protocols are complete, and institution review has been obtained. Surgical implantation is a two-stage process, the first stage of

which has been completed in two tetraplegic subjects and involves surgical restoration of the hand involving tenodeses, tendon transfers, and arthrodeses. The second stage is implantation of the stimulator-receiver. This is to be undertaken after performance of grasping function is stabilized using percutaneous electrodes. This level of performance has been reached with both subjects.

Functional Electrical Stimulation in Upper Extremity Muscles of Spinal Cord Injured Patients

B. R. Seeger, Ph.D. and L. M. Stern, M.B., B.S.

Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: *Adelaide Bone and Joint Research Foundation*

Purpose—A study is being undertaken on the effect of electrical stimulation in upper extremity muscle strengthening of spinal cord injured patients. The aim of the project is to introduce functional electrical stimulation to the treatment program in the spinal injuries unit, in a controlled manner in which physiological benefits are monitored. The significance of the project is that this new treatment modality offers potential for increased independence of spinal cord injured patients through muscle strengthening. The hypothesis to be tested is that FES-assisted exercising of partially paralyzed upper extremity muscles results in significantly greater muscle strengthening in the arms of spinal cord injured patients than equal periods of conventional exercises.

Progress—Four subjects have now entered the project, and it is intended to study approximately six subjects throughout a 12-month period. Baseline measures have been taken of strength of the affected muscles (as measured by a Penny & Giles Myometer), muscle bulk (as measured by CAT scans), range of movement of the appropriate joint, functional skills, and body image.

Future Plans—During a 3-month period of training, using FES or active exercise (to be

randomly decided), monthly strength and range of movement measures will be taken. Retests will then be taken of all the baseline measures.

During a subsequent 3-month training period of active exercise or FES (whichever was not undertaken during the first 3-month period), monthly strength and range of movement measures will again be taken. At the end, retests will be conducted on all the variables measured at baseline. The FES-assisted exercise is to be conducted on as many days each week as each subject can manage. Stimulation is to be 10 seconds on and 50 seconds off at 30 Hz, with sufficient current to cause a full range of movement without the subject's active assistance. Duration is to be for 15 minutes per day on each muscle group during week one, 30 minutes per day in week two, 45 minutes per day in week three, and 60 minutes per day in week four. During months two and three this duration of training is to be maintained, with the subject augmenting the effect of the FES by actively assisting movement.

The active exercise sessions are to consist of an appropriate set of isotonic or isometric exercises selected by the physiotherapist. The duration of exercises is to be the same as for FES, that is, work up to 60 minutes per day for each muscle group.

3. Lower Limb Applications

Walking Restored in Paralyzed Man Using Electronic Orthotics

E. B. Marsolais, M.D., Ph.D.

Veterans Administration Medical Center, Cleveland, OH 44106

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Research activities in this program are directed toward further development of a neuromuscular orthotics system to provide paralyzed persons with specific functional activity, performed smoothly and repeatedly with minimal fatigue.

Progress—Approximately 125 electrodes of a new design were implanted, and found to behave essentially the same as those of the original design. Both portable and laboratory stimulators were modified to allow surface stimulation of the trunk muscles in addition to percutaneous stimulation of the hip, leg, and foot muscles. Predetermined stimulation patterns of the portable sensors can be triggered now with both hand switches and a combination of foot switches; the stimuli are both pulse-width and frequency modulated. Addition of trunk muscle stimulation has allowed better posture, reduced weight borne on the arms, and increased duration of walking.

Closed-loop control of muscles controlling transverse hip motion has been shown to improve stability and resistance to perturbations; it permits both reduced levels of stimulation

during standing and reduced arm support. Computer simulations of the double limb support phase of gait have been developed and will be used in improving walking patterns and developing closed-loop control algorithms for walking. Analysis of force, kinematics, and muscle EMG signals has led to development of new functional activities, such as stepping sideways and walking up and down stairs.

An ankle-foot orthosis and a knee-ankle-foot orthosis have been designed and fabricated (all active subjects have the AFOs) for protection of joints now and for incorporation of sensors in the future. A variable capacitance joint-angle sensor is being tested for use with closed-loop control.

Future Plans—Work is directed toward continued improvement in electrode design and implantation, investigation of the causes of muscle fatigue during FNS use, development of an adaptive controller to obtain longer duration standing and to provide closed-loop control for walking, evaluation of sensor needs, and design of those necessary for the closed-loop system.

Electrical Stimulation of Paralyzed Muscle After Spinal Injury

Charles J. Robinson, D.Sc.; R. J. Jaeger, Ph.D.; R. D. Wurster, Ph.D.; M. Gratzner, M.D.; B. A. Nemchausky, M.D.; R. C. Fruin, M.D.; P. Engelmeier, R.P.T.; J. M. Bolam, M.S.;

Veterans Administration Medical Center, Hines, IL 60141

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Individuals with spinal cord injury have absent or diminished control over muscles that are innervated below the level of their injury. Many of the paralyzed muscles can be activated by electrical stimulation of the nerves

leading to these muscles.

This study attempts to identify the therapeutic benefits of a regular program of electrically induced leg reconditioning and exercise in a general population of veterans whose legs

have been paralyzed by spinal cord injury. The study group consists of individuals with paraplegia and quadriplegia who are patients of the Spinal Cord Injury Service of the VA Hospital at Hines, IL. This predominantly male population provides a diverse mix in terms of level and completeness of injury; actual age and years post-injury; height and weight; and the extent of cardiovascular, renal, urinary, skeletal, neuromuscular, peripheral vascular, cutaneous, and psychological complications brought on as a result of spinal injury. We did not consider individuals with damage to their spinal cord below T11, with severe peripheral vascular or cardiovascular problems, or with pressure sores in areas affected by stimulation, for this protocol.

Progress—To date, we have completed baseline evaluations on 21 qualifying individuals. We

screen an additional three or four potential candidates each month. For the most part, the qualifying individuals had incomplete quadriplegia ($N=10$) or complete paraplegia at T11 or above ($N=7$). For this study we first measured torque and fatigue characteristics produced by a 100-mA stimulus (a 20 Hz train of 0.5-msec compensated monophasic pulses) delivered to the knee extensors via large (2x4 cm) water-soaked surface electrodes in alternating fashion (2.5 sec ON, 2.5 sec OFF). We then placed 18 of the individuals in a twice-daily, 6-day-a-week, 20-minute exercise protocol, with weekly assessment of progress. After four to eight weeks of electrically induced exercise, some participants exhibited large increases in muscle force and fatigue resistance, while others showed little change. We are now attempting to correlate the extent of increases seen (if any) with our other observations.

Sensory Prosthetic Feedback and Application to the FES—Orthosis Systems

Roy Douglas, C.O. ; Paul Larson, M.D. ; Jerrold Petrofsky, Ph.D. ; Chandler Phillips, M.D.

Department of Biomedical Engineering and NCRE, Wright State University, Dayton, OH 45435 and Departments of Neurology and Orthopedic Surgery, School of Medicine, Louisiana State University, New Orleans, LA 70112

Sponsor: Wright State University Foundation

Purpose—The concept of a total neural prosthesis (i.e., simultaneous electronic substitution for both motor efferent and sensory afferent activity) has been proposed. A sensory feedback prosthesis was developed with footload transducers, a "balanced" (carrier-suppressed) modulator, and a vibrocutaneous interface at the subject's skin.

Progress—The system has been reported to provide prolonged balance and upright posture assist in a T4 (complete) paraplegic in whom tactile feedback of feet position was substituted

for visual feedback. This sensory feedback prosthesis can also be combined with an FES orthosis, i.e., FES combined with long leg braces. Currently, the total neural prosthesis (TNP) system performs standup and sit-down as well as prolonged maintenance of upright posture and balance.

Future Plans—Future applications of the TNP are planned which will include walking and optimizing the human operator-system interaction control strategies.

Computer Models for Designing Functional Electrical Stimulation Systems for Paraplegic Standing and Walking

Felix Zajac, Ph.D. and Inder Perakash, M.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Persons with spinal cord injury resulting in paraplegia need to regain functional use of their legs. Functional electrical stimulation (FES) of paralyzed muscles is a potentially useful method for restoring standing and walking functions in paraplegics, but several problems must be solved before FES becomes clinically acceptable. These problems include unreliable stimulating electrodes, insufficient muscle strength, fatigue resistance of the paralyzed muscles, and unavailability of a totally implantable stimulation system. Another problem is the lack of suitable engineering models to study the tradeoffs among alternative FES schemes proposed for controlling paraplegic standing and walking.

We hypothesize that the use of large-scale computer models based on engineering principles is essential to the systematic development of FES systems, just as such models are necessary in controlling aircraft, satellites, and robots, and in planning economic policy.

Our project has three objectives. The first is to formulate a control problem of standing and walking, implement it on a computer, and study the tradeoffs among alternative control schemes. The computer implementation consists of a model of the musculoskeletal system, a model of the feedback sensors, and a feedback controller whose properties can be chosen to optimize a performance criterion. The second objective is to understand the functional significance of individual muscles in maintaining up-

right posture, with emphasis on identifying functional muscular synergies. To accomplish this objective we are using a computer model of the musculoskeletal system and focusing on the mechanics and geometry associated with posture and the imposition of various physical constraints, such as keeping one's knees fully extended or feet flat on the ground. The third objective is to program a graphics workstation to display a real-time animation-like simulation of the human body under FES control.

Progress—In formulating the control problem of paraplegic posture induced by FES, we realized that muscle fatigue is a property of the musculotendon actuator that must be modeled before fruitful FES control studies can be conducted. Emphasis is therefore now directed toward modification of our current musculotendon actuator model. The model of musculotendon actuator dynamics has been amended, however, to account for muscle that is electrically activated by pulse trains, as with FES.

We also realized that it would be desirable to base our model of the knee on a mechanism that more closely resembles patello-femoral-tibial mechanics than our current model does. An engineering model of the musculoskeletal system for use in studies of the geometrical properties associated with postural mechanics has been completed and computer optimization techniques implemented to identify functional muscular synergies.

Open-Loop Control of the Paralyzed Human Knee

R. Nakai ; D. McNeal ; W. Tu

Rancho Los Amigos Rehabilitation Engineering Center, Downey, CA 90243

Sponsor: National Science Foundation

Purpose—Regulation of electrically stimulated paralyzed muscle is being investigated to im-

prove impaired gait in humans. Developing a reliable control system is essential to the even-

tual success of these neuroprosthetic systems. Clinical systems generally use open-loop control of muscle activation, but have limitations. Muscle properties are nonstationary; they depend on muscle kinematics, muscle energetics, and stimulation history. Moreover, electrode characteristics can also be nonstationary. While the natural solution to compensate for these variables is to use closed-loop control, success can still be achieved with open-loop systems. Open-loop systems are demonstrably successful and relatively easy to implement.

Progress—As a first step in developing a reliable open-loop control system, muscle response repeatability has been investigated. Dynamic responses have been matched to a target trajectory by specifying open-loop stimulation sequences to paralyzed muscle. Surface stimulation of the quadriceps muscles of four complete paraplegics permitted dynamic knee responses in a controlled laboratory situation. Response repeatability was assessed before and after a two-month electrical exercise program. Additionally, the effect of the exercise on muscle strength and endurance was measured weekly.

During an experiment, stimulation sequences were specified by an iterative, trial-

and-error procedure such that the knee angle response matched the target trajectory as closely as possible. The target trajectory consisted of extending the knee then returning to a rest flexed position during two seconds of a three-second period. Single period trials were repeated five times before and after a continuous 50 period endurance trial.

Before the exercise program, peak extension typically decreased to less than 70 percent of initial extension by the end of the endurance trial. Following the exercise program, peak extension was maintained, decreasing to only 95 percent of the initial value. Despite maintenance of the peak, the leading and trailing segments of the response demonstrated significant degradation. From these studies, a limited conclusion can be made regarding FES-assisted gait. Our exercise protocol does improve muscle endurance, although muscle responses will degrade nonuniformly during repeated trials.

A hardware and software system are being developed to evaluate various control schemes to regulate the swing phase of gait in paraplegics. Studies of open-loop control will be continued with stimulation of antagonist muscles. In addition, various closed-loop control schemes will be evaluated.

Triggers for Control of Implantable Gait-Assist Systems

J. Symons; D. Nicholson; J. Perry;

Rancho Los Amigos Rehabilitation Engineering Center, Downey, CA 90242

Sponsor: National Institute of Handicapped Research

Purpose—A microprocessor-controlled, implantable gait-assist system is being developed at our center. In this system, triggers will initiate and terminate preprogrammed stimulating sequences. Initial systems will be radio-frequency coupled, but the ultimate goal is to implant all hardware inside the body. Reliable triggers should occur approximately every 25 percent of the gait cycle. Initial systems will use unobtrusive external triggers; later systems will use implantable triggers.

Progress—External trigger sources tested were

footswitches under the heel, first and fifth metatarsals, and the great toe, and pressure sensors in the crutches. Potentially implantable triggers tested were vertical accelerometers (mounted on the upper thigh), the onset and offset of EMG activity of the latissimus dorsi, erector spinae, posterior deltoid and lateral head of the triceps.

The subjects were seven incomplete spinal cord injured persons with walking speeds of at least 30 meters per minute and a four-point reciprocating gait. These criteria were goals for our implant subjects to determine if, at this

level, there are reliable triggers.

Footswitches, vertical acceleration, and the pressure sensors in the crutches were reliable in all subjects. A small standard deviation in trigger timing indicated reliability. The EMG activity of the latissimus dorsi and erector spinae were reliable in five out of seven subjects. The posterior deltoid and triceps were re-

liable in only two subjects. At least one external trigger occurred every 25 percent of the gait cycle. However, reliable potentially implantable triggers occurred only at 0 percent and 50 percent of the gait cycle (left and right foot strike). We will look for other potentially implantable triggers whose timing occurs at 25 percent and 75 percent of the gait cycle.

Computer-Controlled 22-Channel Stimulator for Limb Movement

Ross Davis, M.D. ; Richard Eckhouse, Ph.D. ; James F. Patrick, B.E. ; Ann Delehanty, B.S.

Veterans Administration Medical and Regional Office Center, Togus, ME 04330; MOCO Inc., Scituate, MA; Nucleus Cochlear Pty. Ltd., Lane Cove, N.S.W., 2066 Australia

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The aim has been to modify and test the Nucleus Multi-channel Implantable Hearing Prosthesis as a portable computer-controlled 22-channel neural stimulator. Its new purpose is pattern activation of individual motor nerves in the lower extremities of paraplegic subjects to form functional movements such as exercise, standing, and gait.

Progress—In late 1984 the modified Nucleus Stimulator was completed and delivered. It consisted of the Sanyo MBC-1000 microcomputer with a special interface printed circuit board for its connection to the speech processor interface (SPI): Z80-A processor, programming and erasure circuit. The speech processor (SP) connects into the SPI unit; the SP has an antenna that overlies the receiver stimulator unit (RSU). A Nucleus-adapted connector allowed the use of any or all of the 22 channels at one time. New computer software programs were developed. The Nucleus Radio Stimulator Unit output was calibrated at various temperatures (21.8-39.8 degrees Celsius) over a 6-month period showing no variation in seven tests and slight variation at the lowest temperatures.

Using four barbiturate-anesthetized adult rabbits, it was shown that individual or multiple channels could be computer-controlled in their pulse amplitude, width, and frequency to activate single or multiple nerves resulting in single, co-contractions, and simultaneous bilateral joint movements. To determine the thresh-

old and maximum currents required to produce muscle contractions in human lower extremities, amplitude recordings and nerve diameter measurements were taken during lower extremity amputations in nine patients. Stimulation was carried out at 0.2 msec and 20 pps using a portable, battery-operated, calibrated, constant current stimulator (Cordis Corp., Miami, FL, model 910A). The currents necessary to produce maximum contractions fell consistently below the maximum output capabilities (3.5 mA, 0.4 msec) of the 22-channel stimulator. There was a close correlation between nerve diameter measurements taken at surgery and those obtained from the *Color Atlas of Human Anatomy* (McMinn and Hutchings, Year Book Medical Publishers, Chicago, 1977). These measurements are necessary in planning the size of the spiral electrodes to use in the clinical trials planned in this study.

Future Plans—The microcomputer and interface equipment are being modified into one unit that is a battery-operated, belt-worn microprocessor with the capability of carrying the paraplegic subject's own individual programs for controlling limb movement. Also planned is the production of a totally implantable array of leads, connectors, and electrodes to deliver stimulation to selected motor nerves.

In collaboration with the West Roxbury VA Spinal Cord Injury Service, we will locate five 20- to 30-year-old, healthy, mid to lower

thoracic paraplegics to participate in the clinical trials. It is anticipated that the first subject will receive the implant in late 1986 and will begin the program to first exercise individual

and groups of muscles to increase strength and overcome fatigue. We hope to complete the study having all five subjects using the stimulators within three years.

Lower Limb Function with FES

Robert G. Bosshard, Dip.Ing. ; John D. Yeo, M.D. ; Jean McPhail

Spinal Research Unit, Royal North Shore Hospital, St. Leonards, N.S.W. 2065, Australia

Sponsor: *Spinal Research Foundation*

Progress—Research is based on stimulation of the quadriceps, hamstrings, and common peroneal nerves with a view to achieving standing position and walking. Two groups of patients are used. In the first group are paraplegic patients suffering from a complete upper motor neuron lesion ranging from T4 to T12. In the second group, paraplegic patients suffering from incomplete lesions receive the stimulation

starting 4 to 6 weeks after injury.

Future Plans—Future development in this study involves production of feedback mechanism for foot position and knee angulation. A fully implantable system is also being investigated for improved muscular contraction following nerve stimulation.

A Computer Model for Control of Paraplegic Posture

Felix Zajac, Ph.D. and Gon Khang, M.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—Suitable engineering and computer models need to be developed to study paraplegic posture controlled by functional electrical stimulation (FES).

Computer models, once developed, can be used to design FES-control systems specific to individual paraplegics enabling them to regain their mobility.

Although much is known regarding automatic control system design, the design of FES-control systems is still hampered by such factors as the nonlinearity of physiological characteristics. One of the most important considerations in FES-control system design is the determination of the relationship between FES input (pulse trains) and corresponding limb movement. Another important consideration to control system design is muscle fatigue, which significantly affects paraplegic posture induced by external stimulation.

We hypothesize that development of suitable models for activation dynamics and muscle

fatigue is critical to FES-control system design of user-specific systems and to computer studies of tradeoffs among alternative systems based on different design criteria.

Progress—Our current approach is to model musculoskeletal dynamics, which we decompose into three parts: skeletal dynamics (influenced by external forces such as the ground), musculotendon dynamics, and musculoskeletal geometry. Two planar motions in the sagittal plane are being considered for study: free-standing and crutch-assistive standing. In the skeletal model for free-standing, five body segments including the feet are modeled as rigid bodies assuming bilateral symmetry. The musculotendon dynamics are made up of activation dynamics and contraction dynamics. Since muscle fatigue plays an extremely important role in postural control induced by FES, once muscle fatigue is modeled, we will focus on minimization of muscle fatigue to regulate posture and move-

ment of the lower extremities. Movement of the upper extremities is modeled as an external disturbance. The disturbance rejection control schemes will thus be emphasized.

We have developed reasonably complex models for activation dynamics, contraction dynamics, and skeletal dynamics of the human lower extremities. By using a simplified double-inverted pendulum skeletal model, several

open-loop control laws were applied and found to function well even under small external disturbances (i.e., where the disturbances model movement of the upper extremities). In order to improve system performance, closed-loop control and state estimation are needed. Currently, efforts are being made to model and embody muscle fatigue into the overall system for studies on controllability and observability.

Functional Electrical Stimulation in Dropped-Foot Conditions

L. M. Stern, M.B., B.S. and B. R. Seeger, Ph.D.

Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: *Channel 10 Children's Medical Research Foundation of S.A.*

Purpose—This study will evaluate the effectiveness of functional electrical stimulation in dropped-foot conditions. Improvement of gait by selective stimulation of a child's own muscles would seem to be of considerable benefit if it can be shown to be effective and lasting.

A preliminary study on two children with cerebral palsy was encouraging. Both children had weakness of the extensors of the ankle and walked with a dropped-foot gait. The use of FES resulted in increased ankle dorsiflexion during the swing phase of gait and a more normal heel-toe gait.

We propose to use functional electrical stimulation in ten children with various neurological conditions. The aim will be to assess the effect on gait of stimulation of the peroneal nerve to activate the extensors of the foot. The stimulation will be used on a daily basis for a period of one year. Assessments of the effects of FES will be made at the beginning of the trial, at 6 months, 12 months, and 6 months after cessation of FES.

The following assessments and measurements will be carried out on the children:

1) Muscle bulk of the calf will be measured

by direct measurement of girth and by computed tomography to accurately measure muscle bulk and density of the calf extensors.

2) Assessment of the strength of the ankle dorsiflexors will be carried out using a Penny & Giles Myometer.

3) Gait measurements and a video recording will be made with the subject walking along a straight line. Markers will be placed on bony landmarks. Measurements will be made using a transparent goniometer.

The instrument used will be the Gorenje Mikrofes Electrical Stimulator, which incorporates a heel switch so that electrical stimulation only occurs when the heel is off the ground. The electrodes will be applied to the skin over the peroneal nerve below the head of the fibula. Initially a low voltage will be applied for ten minutes. The voltage will be gradually increased to the limit of comfort and tolerance, and time will be incrementally increased up to four to six hours a day and switched off whenever the child is sitting down. Regular checks of progress, of the skin below the electrode, and of the equipment will be made.

Restoration of Locomotion in Paraplegics Using Functional Electrical Stimulation

J. A. van Alste ; H. J. Hermens ; G. Zilvold ; Dr. H. B. K. Boom

Twente University of Technology; Roessingh Rehabilitation Centre, Enschede, The Netherlands

Sponsor: *None listed*

Purpose—Functional electrical stimulation (FES) for the restoration of locomotion in paraplegics is studied. The research of the two participating institutes is focused on 1) fundamental and clinical problems to achieve an implantable system for the selective artificial stimulation of peripheral nerve fibers, and 2) the optimization of the current possibilities for clinical use of FES.

Progress—Some of the current research projects are:

Nerve stimulation. Multi-electrode configurations for nerve stimulation are studied in rats with the electrodes placed around the nerve and intrafascicular. Recruitment stability and overlap in recruited groups of motor units for different electrodes are investigated. Further, we are investigating the production and use of a platinum electrode array made on a silicon substrate using chip technology for multichannel intrafascicular stimulation.

Stimulation control. In order to achieve reproducible movements we study open- and closed-loop control in animal experiments and in men. In rat experiments the muscle has been loaded with a servo-controlled mechanical load. In human subjects the transfer sit-to-stance is studied using specially developed equipment. The subject is in a supine position on a bench, while his legs exercise against an adjustable resistance force. The equipment is used to study open-loop stimulation, system identification, and closed-loop adjustment of the open-loop stimulation pattern.

Assessment of kinematic information. The

control of functional movements by artificial stimulation can be improved by feedback of kinematic information. We therefore studied the use of accelerometers because they offer the potential for future implantation and whether the subject is lying, sitting, or standing can easily be detected. We developed a theory for assessment of the leg segment angles without integration for two-dimensional rotations. We validated the theory by measurements on a pendulum and with two-dimensional movements of the lower extremities during stance phase.

Clinical application of test and training equipment. In clinical applications, surface electrodes are still most important. The electrode configuration and electrode position are important for optimizing the reproducibility in muscle recruitment. Therefore methods are developed and tested.

The active training of paralyzed muscles to work needs special equipment. The training for strength of the muscles involved in the sit-to-stance transfer is studied using the apparatus described previously.

Muscle endurance is trained on a bicycle ergometer, in which the stimulation patterns are synchronized with the angle of the pedals. The angular velocity is controlled by a feedback control loop.

The cardiac condition of the subject is estimated from the response to graded exercise testing using a specially developed arm ergometer. This exercise may be combined with leg exercise induced by electrical stimulation.

4. Other

Fitness Improvements and Physiological Responses to FES Exercise

Roger M. Glaser, Ph.D., and A. G. Suryaprasad, M.D.

Veterans Administration Research and Development Service, Dayton, OH 45428

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to compare the acute and chronic exercise responses of functional electrical stimulation (FES) of the lower limbs to standard arm crank ergometry (ACE) and “hybrid” exercise (i.e., FES plus ACE) in elderly VA subjects versus their young able-bodied and disabled counterparts.

The study will be completed in two phases. Investigations of the metabolic and cardiorespiratory responses to FES, ACE, and “hybrid” exercise will be completed on young able-bodied males and wheelchair users at the Laboratory of Applied Physiology, Wright State University. Subsequently, the acute responses to FES, ACE, and hybrid exercise as well as longitudinal training studies will be initiated with the elderly VA population, domiciled at the VAMC in Dayton, OH, for comparison to the younger men.

Cardiorespiratory and metabolic assessments will be made by well established tech-

niques. The optimal exercise protocols using FES, ACE, and hybrid exercise will be developed in the younger population for application to the older men. Peripheral responses to acute and chronic treatments will be assessed via a modification of impedance plethysmography for estimation of limb blood flows. Central hemodynamics will be assessed using impedance cardiography and CO₂-rebreathing cardiac outputs.

Progress—We have studied 20 younger able-bodied subjects and wheelchair users. Optimal exercise protocols have been developed and both acute and chronic responses are now under study in the younger population. Portions of this work have been recently presented at the Fifth International Symposia on Adapted Physical Activity, in Toronto, Ontario, Canada, and data have been published in *Clinical Research*, *Federation Proceedings*, and by IEEE.

Predictive Factors for Restrengthening Paralyzed Muscle by Electrical Stimulation

Charles J. Robinson, D. Sc.; R. J. Jaeger, Ph.D.; M. Gratzner; B. A. Nemchausky, M.D.

Veterans Administration Medical Center, Hines, IL 60141

Sponsor: Paralyzed Veterans of America Spinal Cord Research Foundation and Vaughan Chapter

Purpose—Electrical stimulation of paralyzed muscle could be potentially useful for many persons with spinal cord injuries, however little work has been done to document this assumption. Furthermore, electrical stimulation is not presently being used on a large scale for persons with spinal cord injuries, because physicians cannot predict how various patients will respond to electrical stimulation. The goal of this project is to develop a set of tests that will help physicians to predict the responses of mus-

cles to electrical stimulation.

Progress—We have begun preliminary studies on determining predictive factors with 18 patients of the Hines VA Spinal Cord Injury Service. All patients have given their informed consent to the research protocol. This predominantly male population provides a diverse mix in terms of level and completeness of injury, actual age and years post injury, height, weight, and medical and psychological compli-

cations brought on as a result of spinal injury. We have not considered individuals with damage to their spinal cord below T11, with severe peripheral vascular or cardiovascular problems or with pressure sores in areas affected by stimulation, for this protocol.

Preliminary Results—We completed initial evaluation on these patients using electromyographic radiographic (CT scan), and neuromus-

cular techniques, before entering them in a 4-to-8-week protocol. In this protocol we are stimulating their thigh muscle force and fatigue during 20-minute exercise sessions, tracking changes in thigh muscle force and fatigue characteristics from week to week. Preliminary results suggest a possible correlation between muscle mass (as determined by the CT scan) and initial response to electrical stimulation.

Electrical Stimulation of Osteogenesis Using Selected Techniques

Thomas J. Baranowski, Jr., Ph.D.; Myron Spector, Ph.D.; James Roberson, M.D.;

Veterans Administration Medical Center Research and Development Service, Decatur, GA 30033; Department of Orthopaedics, Emory University School of Medicine, Atlanta, GA 30303

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This research project involves the use of various, selected, electrical stimulation techniques for bone growth and repair. The overall goal is to determine an effective stimulation technique for evaluating the appropriateness of electrical stimulation therapy to remobilize patients with loose prosthetic devices (trauma and irritation present) and patients with osteopenia (trauma and irritation absent). The specific aims are to: 1) define the dose response relationship in magnetic field amplitude for electromagnetic stimulation (EMS) produced by a sinusoidal waveform; 2) determine whether trauma and irritation are required with EMS produced by either a sinusoidal or square-pulse burst waveform; and 3) compare the efficacy of direct current stimulation (DCS), EMS by a sinusoidal waveform, and EMS by a square-pulse burst waveform in the same animal model.

Throughout this project, the tissue site selected for electrical treatment will be the rabbit tibial medullary canal. Surgical intramedullary insertion and implantation of a flexible, nonmetallic rod will be employed to produce trauma and irritation in intact tibia where indicated by experimental design. Such trauma and irritation may be necessary to obtain cells responsive to electrical stimulation treatment. The biological response within the medullary canal will be evaluated by histomorphometric quantitation of

new bone formation, necrotic tissue, and selected cell types.

Progress—Originally, restraint and anesthesia of the animals, used by others in previous similar experiments, were to be employed in this research to permit daily placement of electrical devices as well as the stimulation treatment. However, the excessive restraint, prolonged anesthesia, and consequent inactivity of the animals usually result in a loss of weight, health, and not infrequently, life. To avoid these complications, a system of jacket, tether, and electrical swivel was developed to permit routine electrical stimulation treatment of animals with any stimulation technique. It was believed that such a system would help to establish a more accurate index of the biological response to electrical stimulation with *in vivo* animals.

The jacket-tether-swivel system allows the animal to have freedom of movement within its cage with access to both food and water *ad libitum*. A group of 12 animals has recently completed treatment with electromagnetic stimulation by a sinusoidal waveform of three different amplitudes using the above system. The group sustained the treatment without restraint or anesthesia and with no loss of weight, health, or life. The biological response to the electromagnetic stimulation described above is currently being evaluated by histomorphometric

analysis. The development of the jacket-tether-swivel system permits electrical stimulation treatment of animals in a humane and comfortable manner.

Future Plans—With the system now reduced to routine practice, treatment of the additional animal groups necessary to achieve the specific aims of this project are scheduled for completion over the next year.

Value of Electrical Stimulation on Fertility in Male Patients with Spinal Cord Dysfunction

L. K. Lloyd, M.D.

Department of Surgery—Division of Urology, Research and Training Center in Spinal Cord Dysfunction, University of Alabama at Birmingham, AL 35294

Sponsor: *National Institute of Handicapped Research*

Purpose—Infertility is a major problem among male spinal cord injured (SCI) patients. In fact, infertility rates range from 99 percent for neurologically complete quadriplegics to 90 percent for neurologically incomplete paraplegics. This study seeks to 1) determine optimal conditions for producing seminal emission via electrical stimulation of the pelvic sympathetic nerves; 2) compare electrical stimulation with strong vibratory stimulation of the genitalia in eliciting seminal emission in male SCI patients; 3) determine if repeated stimulation improves semen quality (sperm count, motility, and morphology); 4) determine if intermittent testicular cooling improves semen quality; 5) relate success or failure of seminal emission production to neurolevel and extent of spinal lesion, urodynamic assessment of lower urinary tract function and incidence of recurrent urinary tract infection; and 6) artificially inseminate a male SCI patient's partner who had been unable to be impregnated since the patient's injury.

Progress—Male SCI patients voluntarily participating in the study are randomly assigned

to electrical stimulation or vibratory stimulation groups. Seminal emissions are acquired and the sperm examined for viability. Patients failing to produce viable sperm in either group undergo stimulation with testicular cooling. Viability of sperm produced is determined. Success or failure of seminal emission production is assessed statistically. Female partners of patients with satisfactory sperm production by either modality will be evaluated physically and, if in good health, artificially inseminated.

Preliminary Results—Six patients have been entered in the study. All six were caused to ejaculate via rectal stimulation. All of the patients had adequate sperm counts but none had more than 10 percent motile sperm. Therefore, artificial insemination was not performed. Only one patient was able to ejaculate with the assistance of a vibrator.

Future Plans—Data collection will continue until 1990. The final year of the project will include data analysis.

Cardiovascular Circulatory Dynamics in Quadriplegics With and Without Functional Electrical Exercise (Active Physical Therapy)

Damianos Danopoulos, M.D.; Paul Kezdi, M.D.; Jerrold Petrofsky, Ph.D.; Chandler Phillips, M.D.; Ralph Stacy, Ph.D. NCRE, Wright State University and Department of Biomedical Engineering, Cox Heart Institute, Dayton, OH 45435

Sponsor: *Veterans Administration (in part)*

Purpose—The purpose of this study was to demonstrate selected cardiovascular training ef-

fects secondary to functional electrical exercise for quadriplegics.

Progress—Eight quadriplegic subjects engaged in 12 weeks of exercise bicycle ergometry that utilized closed-loop control of movement of the paralyzed skeletal muscle. Baseline evaluation of cardiovascular status (including response to supine and head-up tilt) were initially performed. Post-training period (after 12 weeks) of

the cardiovascular status of the quadriplegics indicated a statistically significant increase in resting systolic blood pressure, heart rate, and cardiac index. Efforts are directed toward understanding fundamental material properties of cardiac muscle in quadriplegics and potential changes in functional electrical exercise.

Electrical Muscle Stimulation for the Prevention of Pressure Sores:

1) Pressure Studies

Simon P. Levine, Ph.D. ; Ronald L. Kett, M.S. ; Paul S. Cederna, B.S. ; Susan V. Brooks, M.S.

Rehabilitation Engineering Division, Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center, Ann Arbor, Michigan 48109; VA Medical Center, Ann Arbor, MI 48105

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Pressure sores (decubitus ulcers, ischemic ulcers, etc.) represent a severe and costly problem for many disabled individuals. This is particularly true for those who are wheelchair-dependent and have sensory loss. A research program has been implemented to determine whether electrical muscle stimulation (EMS) can be used to prevent the formation of pressure sores.

It is generally accepted that the primary cause for the development of pressure sores is the local restriction of blood and lymph vessels due to external forces exerted on the tissue. There are a number of mechanisms through which EMS can possibly help prevent pressure sores: 1) tissue undulation and variations of seating interface pressures permitting increased blood and lymph flow; 2) increased local blood flow to muscle and surrounding tissue in response to muscle contraction; 3) increased blood and lymph flow due to muscle pump activity; and 4) long-term effects of chronic stimulation, including increased muscle bulk and strength, increased vascularization, and changes in tissue properties such as metabolic and muscle twitch characteristics.

These positive effects must be weighted against possible negative effects to develop stimulation parameters that are effective in preventing pressure sores. Possible negative effects include increased intramuscular pressure, muscle oxygen requirements, metabolite production, fatigue, heat, and sweat.

Progress—Pilot studies have been performed to study the tissue undulation and seating interface pressure variations produced as immediate and dynamic effects of EMS. Bilateral surface stimulation of the gluteus maximus has been performed on able-bodied and spinal cord injured subjects while seated in a wheelchair. Varying stimulation frequencies and intensities have been used but have been limited to those that produce at most a 1-inch medial lateral movement at the knee while seated. Seating cushions used in these studies have included a sling seat, 1-inch gel pad, temper foam, polyurethane foam, and a ROHO cushion.

Interface pressure measurements have been made using two different pressure measurement pads. Pressure measurements made using a Scimedics pressure pad evaluator have shown seating interface pressure variations as great as 15 mm Hg even with these relatively low stimulation intensities. Pressure measurements made using a TIPE pressure pad have shown a redistribution of seating interface pressures during stimulation. (A specialized computer interface for the TIPE pad is reported elsewhere in this publication.)

Future Plans—Results of ultrasonic imaging of the buttocks during stimulation are reported separately in this publication. Blood flow measurements using radioactive tracers are currently underway with both able-bodied and paralyzed subjects. Clinical trials to determine prac-

tical efficacy of using electrical muscle stimulation to prevent pressure sores is planned for the near future. Both short-term, dynamic ef-

fects and chronic effects as well as their interactions will be studied.

Electrical Muscle Stimulation for the Prevention of Pressure Sores:

2) Ultrasonic Shape Imaging Studies

Simon P. Levine, Ph.D. ; Paul S. Cederna, B.S. ; Susan V. Brooks, B.S.

Rehabilitation Engineering Division, Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center, Ann Arbor, MI 48105; Veterans Administration Medical Center, Ann Arbor 48105

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The rationale for using electrical muscle stimulation (EMS) for preventing pressure sores is presented above (Electrical Muscle Stimulation for the Prevention of Pressure Sores: 1) Pressure Studies). This report covers work on ultrasonic imaging of the buttocks both with and without stimulation. The purpose of this study is to determine buttock shape and tissue reconfiguration that occurs with stimulation. The value of this type of investigation stems from a conceptual model of pressure sore formation based on tissue distortion.

Distortion of tissue results mostly from the application of uniaxial forces. Body tissue, which is essentially incompressible, must laterally expand when subjected to uniaxial forces in order to maintain constant volume. This tissue distortion tends to collapse blood and lymph vessels and thus promote ulcer formation. Hydrostatic loading, on the other hand, avoids tissue distortion and its associated restrictions of blood and lymph flow.

Progress—An ultrasonic pulse echo image acquisition system (U.I. Octoson-Ausonics Corp.) has been used to image the buttocks of five able-bodied subjects under various seating conditions. The Octoson has a large water bath that can be covered with a plastic membrane and was used to produce a transverse plane image of the buttocks. Ultrasonic images have been generated under three conditions:

A) Buttocks suspended in water with no external load and no stimulation. The subjects supported themselves by their arms with hips

flexed at approximately 90 degrees and buttocks suspended in the Octoson water bath.

B) Subject seated on plastic membrane with no electrical stimulation simulating the standard seating interface condition.

C) Subject seated on a membrane with electrical stimulation applied. This shows the effect of stimulation on the buttock tissue configuration during sitting. Bilateral stimulation at 50 Hz was used with intensity set as described in the pressure study.

Preliminary Results—Noticeable distortion of the buttocks was observed in trial B compared to trial A as would be expected. In trial C, the effects of the evoked buttock contraction were clearly visible. The shape of the buttocks was significantly changed from trial B toward that of the suspended buttocks as observed in trial A. Similar results have been obtained for all five subjects tested so far. These results of the trials show that low level stimulation can produce a significant change in buttock shape and configuration.

Future Plans—Arising from this work will be blood flow studies with radioactive tracers and clinical trials to test two hypotheses: 1) dynamic undulation produced with electrical stimulation can increase blood and lymph flow and help prevent pressure sore formation; and 2) reconfiguration of the buttocks through stimulation can help reduce tissue distortion and blood and lymph vessel occlusion to help prevent pressure sores.

Rehabilitation of Fast and Slow Skeletal Muscle

Richard L. Lieber, Ph.D.

University of California at San Diego and Veterans Administration Medical Center, San Diego, CA 92161

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The purpose of this project is to document the response of “fast” and “slow” skeletal muscle to transcutaneous electrical stimulation. The experimental model used in the m. tibialis anterior (TA, fast) or m. soleus (SOL, slow) from the New Zealand white rabbit. Muscles are cast immobilized and stimulated at either 10 Hz or 50 Hz for 1 hour per day, 5 days per week for 4 weeks. Following the treatment period, muscle contractile and histochemical properties are measured.

Progress—Initial studies were directed toward measuring the baseline properties of the atrophied TA and SOL. It was demonstrated that casting angle had a profound effect on the muscular response. For example, when the TA was cast at about 10 degrees plantarflexion, hypertrophy, not atrophy, resulted. In addition, the

SOL, a predominantly slow muscle, atrophied to a much greater extent and demonstrated a partial slow-to-fast fiber type transformation during the immobilization period.

With this baseline information in hand, present studies are directed toward measuring the muscular changes induced by either 10 Hz or 50 Hz transcutaneous stimulation. Initial studies demonstrated that 50 Hz intracast stimulation results in increased intramuscular pressure to the extent that muscle necrosis occurs. Also, because the TA fatigues quickly in response to 50 Hz stimulation, 10 Hz stimulation actually has a greater strengthening effect over the 4-week treatment period. We are now experimenting with different stimulation protocols in order to minimize TA fatigue during stimulation.

Treatment of Spastic and Paretic Muscles in CP Children

Stanislav Rebersek, D.Sc.

Edvard Kardelj University, Ljubljana, Yugoslavia

Sponsor: *National Institute of Handicapped Research; Slovene Research Community, Ljubljana, Yugoslavia*

Purpose—The aim of this study is the improvement of present treatment procedures used for therapy of spastic and/or paretic legs in cerebral-palsied children. The main therapy is afferent and efferent electrical stimulation with various stimulation modalities. An additional therapeutic procedure machine ranging at all three joints (ankle, knee, and hip) is proposed.

Progress—Since the project started we have succeeded in introducing this kind of therapy only for the ankle joint. Completion of the necessary equipment will enable intensive therapy of all three joints on both legs. The main goal of all therapeutic procedures is prevention or at least postponement of surgical intervention at an early age. According to specific neurological

and biomechanical deficits of each child, both kinds of therapy will be combined.

The progress of each patient is estimated through various objective tests, which are divided into two groups: functional tests and hyperexcitability tests. In the first group are gait measurements and posture stability tests; in the second group are tendon reflex tests and biomechanical measurements such as a pendulum test and resistance to passive movement. Through these various tests possible neurophysiological mechanisms responsible for biomechanical deficit are also studied.

Since the study is mostly oriented to long-term effects we are not able to present definitive results at this time.

V. Functional Assessment

Ambulatory Physiological Monitoring Device

A. Bennett Wilson, Jr., B.S.M.E.; and Oscar Aizcorbe, M.D.

Department of Orthopaedics and Rehabilitation, University of Virginia Medical Center, Charlottesville, VA 22908 and Veterans Administration Medical Center, Salem, VA 24153

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The collection of objective data on the effect of various lower limb prosthesis designs on performance of amputees in the past has been limited essentially to oxygen-uptake measurements and locomotion data taken in laboratory settings. Data taken under such artificial conditions are expensive, and can be misleading because of the limitations inherent in the present systems. As a result, evaluation groups have relied heavily on subjective data reported by subjects using experimental devices. The results are not usually as reliable as investigators consider desirable.

One of the most useful indicators of improved function, comfort, or both, is any change in activity level, or the number of steps taken by the subject over given periods of time. Step counters have been used in the past but have not proven to be useful because the steps taken were not recorded against time in a significant manner.

J. MacGregor, as a Ph.D. candidate, proposed the use of an ambulatory monitoring system that would provide three channels of information recorded against time for a 24-hour period (MacGregor, J. "Rehabilitation Ambulatory "Monitoring," Ch. 18 in *Disability—Proceedings of a Seminar on Rehabilitation of the Disabled*, Kenedi RM, Paul JP, Hughes J, eds. MacMillan, 1979). He used only two channels, one for electrocardiographic signals and one for signals from an accelerometer placed on the chest, to record heartbeats and steps against time.

Progress—Modifications of the MacGregor system permit recordings of heartbeats and steps against time in both analog and digital displays with excellent reliability and extreme accuracy. In addition, whether the patient is standing or sitting is recorded. Counts of steps and heartbeats can be made over periods as short as 20 seconds and as long as 24 hours. The equipment is light enough and sufficiently compact so that ordinary activities of the subject are not impeded.

The system is now being used routinely in the evaluation of the below-knee sockets with flexible brims by the Arthritis Rehabilitation Research Program at the University of Virginia. Other departments and research programs have shown a strong interest in this system.

Preliminary Results—It is believed that the ambulatory physiological system now makes possible scientific evaluation not only of prosthesis components, but of almost any treatment program involving locomotion.

A paper has been written for submission to the *Journal of Rehabilitation Research and Development*. Presentations on the system were prepared for the Annual Conference of the American Physical Therapy Association, June 1986; the Annual Conference of Region VI of the American Orthotic and Prosthetic Association, June 1986; the 39th Annual Conference of the Association on Engineering in Medicine and Biology, September 1986; and the IEEE/EMBS Annual Conference in November 1986.

Long-Term Ambulatory Physiological Surveillance Equipment (LAPSE)

James MacGregor, M.Sc., Ph.D., F.I.Biol.

Bioengineering Unit, University of Strathclyde, Glasgow G4 ONW Scotland

Sponsor: *University of Strathclyde*

Purpose—Characterization of the specific extent of a physical handicap and its response to treatment is difficult. The majority of techniques employed are subjective or, at best, are performed on a relatively short time scale in the artificial environment of the hospital or clinic.

LAPSE is intended to study patients over a two-to-three-day span without interfering at all in the intellectual, physical, or social life of the subject. It is based on the acquisition of a very large statistical sample of data relating to patient activity, including changes in posture, mobility, and the associated physiological effort,

i.e., heart rate concurrently observed.

Progress—An earlier system based on a miniature analog tape recorder has been superseded by solid-state microprocessor-controlled datalogging elements that can be used to measure or define the lifestyle of the individual patient. Changes brought about by the different managements introduced can be clearly seen from these measurements. Our work is still proceeding on the development of suitable transducers complementary to those already developed. A wide range of clinical applications are under consideration for early implementation.

Predictive Assessment in Prescription of Functional Aids for the Motor Disabled

Michael J. Rosen, Ph.D.

Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *National Institute of Handicapped Research*

Purpose—The goal of this project is to develop data, methods, and theory on which to base prediction of functional gain from therapies and technological intervention. It was proposed that this concept be applied to three handicapping conditions: 1) disabling tremor of the upper extremities; 2) "equinus" and other spastic gait abnormalities; and 3) loss of vocal communication due to impaired articulatory motor control. During the past year, considerable progress has been made in the first two areas. (Work in the last of these areas has for the past two years been supported by other funding.) The motivation for this REC project derives from the impracticality of exhaustive try-it-and-see evaluation of modes of intervention in the clinic.

Progress—During the past year, extensive data have been analyzed from a study of alcoholics with essential tremor conducted collaboratively with Dr. Mindy Aisen, former visiting scientist in the Mechanical Engineering Department at

MIT, and Dr. Jorge Romero at the Veterans Administration Medical Center at Brockton. Subjects in that study performed wrist extension/flexion pursuit tracking and postural maintenance tasks presented visually. In some trials, angular displacement was required and various masses were added to the hand. In other trials, isometric torque was required and the display gain was varied.

Preliminary Results—The results show that most of this group of eight subjects had tremor characterized by two frequency peaks, one at 8 to 10 Hz and another at 4 to 7 Hz. The two spectral bands behaved very differently with respect to their variation with the experimental parameters. The lower frequency component was influenced by biomechanical factors, whereas the higher frequency component was not. This is significant in part because it is distinctly different from the response to load factors observed in intention tremor measured in

earlier studies by this group. This outcome supports our expectation that the sequence of mechanical load application and spectral processing may serve as a clinical "probe" into a patient's tremor, one which generates a description of tremor at a level closely related to its physiological mechanism. The working assumption is that such a description stands a greater chance of being predictive of the success of a therapeutic approach than standard methods of clinical evaluation and classification.

In the area of spastic gait, work has continued on the development of the wearable, computer-controlled ankle orthosis simulator. This system, developed here by Brian Maki, applies energy-dissipating torques about the ankle under the control of software running at the time of the experiment on a laboratory mini-computer. By applying different control algorithms, various damping-like load profiles can be tried with changes only in software. The goal is to find the load that minimizes

"equinus" and back-kneeing without unacceptable other effects on gait. In order to make the process of identification of optimal values for load parameters more rapid, Tom Hedman had developed an on-line search algorithm that computes the value of an optimization function after each walking trial and adjusts the value of damping constant for the next trial. This methodology has been tried on four cerebral-palsied subjects during the past year. The program was technically successful in all cases, and in one subject a significant optimum with respect to damping constant was found. This outcome supports two tentative conclusions: the technique of human-interactive stimulation can be a practical clinical method for customizing a complaint ankle orthosis for a particular client (or for establishing its ineffectiveness); and, it appears that such an assessment will be essential since the clinical observation of "equinus" does not necessarily predict the effectiveness of such a brace.

Improved Methods of Quantification of Function/Performance

George V. Kondraske, Ph.D.; Vert Mooney, M.D.; George Wharton, M.D.; Susan S. Smith, M.S., P.T.; Raymond L. Dabney, B.S.O.T.

Electrical and Biomedical Engineering, University of Texas at Arlington, Arlington, TX 76019; Orthopaedic Surgery Division, University of Texas, Health Science Center at Dallas 76235; The Dallas Rehabilitation Institute 75235; Physical Therapy, University of Texas, Health Science Center at Dallas 76235

Sponsor: *University of Texas at Arlington; University of Texas Health Science Center at Dallas; Dallas Rehabilitation Institute; Dallas Rehabilitation Foundation*

Purpose—The University of Texas at Arlington (UTA), the Dallas Rehabilitation Institute (DRI), the University of Texas Health Science Center at Dallas (UTHSCD), and the Dallas Rehabilitation Foundation (DRF) have formed a research consortium that established the Center for Advanced Rehabilitation Engineering (CARE). The primary research goal is to develop improved methods for quantification of human performance/function in handicapped individuals. Central to this effort is the computer-automated measurement system developed in the joint UTA/UTHSCD Biomedical Engineering Program.

Progress—The system includes measurements of mental alertness, vision, hearing, speech,

steadiness, reactions, tactile sensations, manual dexterity, range of motion, speed and coordination, postural stability and control, selected activities of daily living, strength, resistance to passive motion, and fatigue. Research to evaluate the system's reliability and utility for assessing performance and the function of handicapped individuals has progressed. The system is also used to help answer clinical and scientific research questions.

Future Plans—The laboratory is being expanded to include assessments of gait and proprioception as well as some of the above functions at new body sites. New instruments, a database, and test result report software continue to develop.

Development of a Computer-Automated System for Functional Assessment

George V. Kondraske, Ph.D.; Wolf W. von Maltzahn, Ph.D., P.E.; Khosrow Behbehani, Ph.D.; Michal Chwialkowski, Ph.D.; J. Robin Richmond, Ph.D.

Electrical and Biomedical Engineering, Center for Advanced Rehabilitation Engineering, University of Texas at Arlington, Arlington, TX 76019

Sponsor: *National Institute of Handicapped Research; Dallas Rehabilitation Foundation; University of Texas at Arlington Organized Research Fund*

Purpose—We have developed a computer-automated system to quantitatively measure a broad selection of sensory and motor functions. The objectives of this project are to further develop and expand the basic system and to prepare and evaluate two complete prototype systems for evaluation and application studies at our clinical settings, the University of Texas Health Science Center at Dallas (UTHSCD), and the Dallas Rehabilitation Institute (DRI). In this battery of tests, each function is measured during very specific, simple, and short-duration tasks that usually involve responses to computer-generated stimuli. Special-purpose transducer modules have been designed to convert responses into voltages for digitization by computer. Signal processing algorithms compute single number results for most tests that quantitatively indicate the level of a specific function.

Progress—A database management system, with interactive test result inspection capabilities, has been implemented. At present, the database contains more than 2000 subject records of sensory and motor function, divided approximately equally between patients with various handicaps and normal data that are essential to interpret patient findings properly. It is possible, through a computerized process, to collect any or all of more than 200 measures of sensory and motor function, deposit results in the database, and examine an individual's results by comparison to a selected subset of the normal population. Results are expressed in terms of standard deviations from the selected comparison population. During the past year, new cooperative research (which allows replications of the system to be used and evaluated at external sites) has begun between the San An-

tonio Sports Medicine and Rehabilitation Clinic, St. Paul Hospital Human Performance Center (Dallas), National Rehabilitation Hospital (Washington, DC), Wadsworth VAMC (Los Angeles), and Dallas VAMC. This added to other external sites, all linked together via the common database, at Chicago Shriners Hospital and Cordis Corporation (Miami).

Preliminary Results—The Biocurve Tracer, a large-volume three-dimensional digitizer, has been evaluated for obtaining range-of-motion measures in simple joints as well as the spine. In addition, a method has been developed to use it to measure spinal curvature. Evaluations indicate results comparable to other techniques that do not offer the ease of administration and computer-based logging of results.

While many system measures have been well established and are in regular use, recent work focused on extracting new meaningful measures during established protocols, at no expense of test administration time. Specifically, additional measures of coordination, tremor, fatigue, and posture (via the Biocurve Tracer) have been identified. In addition, quantification of speech motor function has received emphasis during this period. A systematic function-oriented approach, based on our previous measurement philosophy for extralaryngeal sites, has been established and is being evaluated experimentally in this study.

Software for personal computers has been developed to allow interface to the database and display of individual results as well as test-retest comparisons in various easy-to-interpret forms, such as graphical mappings of function to anatomy. Color-coded schemes are used to represent levels of relevant sensory and motor functions at each site. Work in expert systems

to provide more refined information to neurologists, orthopaedists, physical therapists, occupational therapists, and vocational experts has also progressed. One such system employs function measurements; the database; mapping

rules (for function to body sites and actions, muscles, and innervation); and dysfunction pattern rules in an attempt to localize and quantify the extent of lesions in the neuromuscular system.

Clinical Evaluation and Application of a Computer-Automated System for Functional Assessment—Part 1

Vert Mooney, M.D.; Susan S. Smith, M.S., P.T.; George V. Kondraske, Ph.D.; Ron Tintner, M.D.

Orthopedic Surgery Division, Physical Therapy, Electrical and Biomedical Engineering and Neurology, University of Texas Health Science Center at Dallas, Dallas, TX 75235

Sponsor: *National Institute of Handicapped Research; Dallas Rehabilitation Foundation*

Purpose—A prototype of the Center's computer-automated human performance measurement system is being evaluated for test-retest repeatability and effects of age, gender, and handedness while gathering normal sensory and motor function data, as well as short-and-long-term stability of patient data. Other research studies involving rehabilitation and investigative applications of the system are being carried out at this center in cooperation with local investigators.

Progress—Significant progress has been made in measurement of screened normal individuals to establish a sensory and motor function database. To date, norms for approximately 150 measures have been obtained with the following age breakdowns for data records: 2 (≤ 10 yrs), 32 (10-19 yrs), 494 (20-29 yrs), 201 (30-39 yrs), 60 (40-49 yrs), 87 (50-59 yrs), 123 (60-69 yrs), 59 (70-79 yrs), 9 (≥ 80 yrs). Many subjects were tested and retested no less than 1 week and no more than 2 weeks later. Test-retest data are being used in large-scale studies of reliability and learning effects. In one study, results indicate that 87 of 102 measurement variables included show very good reliability (reliability coefficient ≥ 0.75), and only nine variables indicated significant learning effects. Timed activities of daily living measures were shown to be the least reliable.

Preliminary Results—Data collection for short-term learning (same subjects evaluated repeatedly on 5 consecutive days) and effects of technician and test site (same subjects evaluated at different sites by same technician as well as same site by different technicians) have been completed and analyses are under way. Results are important to document potential sources of measurement variability with the system in typical clinical use. Long-term changes in normal and handicapped function, where subjects are recalled annually for retests, are being studied. Thus far, more than 60 subjects have responded and have been retested.

Patients with progressive neurologic diseases such as Parkinson's disease, multiple sclerosis, myasthenia gravis, Huntington's disease, and chronic low back pain are also being characterized and studied. In 45 post-surgical low back pain patients, preliminary results show some loss of function compared to age-matched norms in every function category measured (including mental status and upper extremity function), although, in general, the loss is greater for lower extremities and whole body balance and reaction functions.

To begin to integrate the system into routine clinical use, local clinicians have been invited to refer individual patients for function measurement workups. Clinicians are provided with printed standard report forms and, if requested, interpretation assistance.

Clinical Evaluation and Application of a Computer-Automated System for Functional Assessment—Part 2

George Wharton, M.D.; George V. Kondraske, Ph.D.; James J. Carollo, M.S.; Margaret Wise, M.S., O.T.R.
Dallas Rehabilitation Institute, Dallas, TX 75235 and Electrical and Biomedical Engineering, University of Texas at Arlington 76019

Sponsor: *National Institute of Handicapped Research; Dallas Rehabilitation Foundation*

Purpose—A second prototype of the Center's computer-automated human performance measurement system is being evaluated clinically and used to conduct studies of rehabilitation significance at the Dallas Rehabilitation Institute (DRI). Work at this site has been under way to characterize the function of patients with head injuries, spinal cord injuries and peripheral neuromuscular damage, cerebral palsy, amputated limbs, spinal pain, and arthritis. Data are being used to develop functional profiles and databases of these conditions, as well as to document effects of therapy and recovery trends. Over the past three years, over 650 evaluations have been made on 274 subjects.

Progress—As experience with these patient groups increased, several modifications to test devices were found necessary and adaptations were implemented. Progress in studies of system evaluation and database establishment parallels that detailed for our UTHSCD clinical site, as these studies were jointly undertaken.

Progress continues in the study of head injury patients. The effects of a cognitive remediation program on functional performance are being studied in a subset of head-injured patients, with measurements before entry and at 2-month follow-up intervals. In addition, research to predict level of independence in tasks such as grooming and feeding for basic quantitative measures of function has been initiated.

An expert system approach was utilized. Initial results indicated high potential for successful objective classification. A similar approach was utilized to screen head-injured subjects for driver training.

Work continued to progress in quantitative characterization of spinal-cord-injury patients and their rehabilitation progress. A total of 166 evaluations were made, many of which represent retests at regular intervals. This subset database will serve as the basis for evaluating the efficacy of therapeutic regimens as well as for increasing the knowledge regarding spinal cord injury recovery. In addition, handicapped volunteers began to establish a database of stable wheelchair-bound individuals who will participate in studies of long-term exercise value.

Preliminary Results—A questionnaire research survey of quantification requirements to evaluate functional electrical stimulation (FES) effectiveness was also carried out as a first step toward meeting needs in this area. Among findings, it was documented that of the 116 measurements listed in the survey, only 8 were clearly determined to be unacceptable, while 82 were considered to be at least "effective." Results will be used to assess the system's current measurement capabilities in this domain, to promote the use of quantitative measures in documenting FES effectiveness, and to map out research priorities for the future.

Quantification of Mobility Performance for Functional Assessment, Diagnosis, and Therapy of Neuromuscular, Skeletal, and Synovial Joint Dysfunctions

Robert W. Mann, Sc.D., and Derek Rowell, Ph.D.
Harvard University—Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *National Institute of Handicapped Research; National Science Foundation*

Purpose—Functional assessment of disabling mobility disorders requires reliable methods for

quantitatively documenting the kinematic and dynamic state of the movement-impaired indi-

vidual. Such methods can enhance confidence in determining the effectiveness of surgical and/or rehabilitative procedures. This project involves an assessment process that goes beyond documenting the status of the patient by providing simulations of the consequences of different muscular skeletal surgical procedures, thereby affording the medical practitioner the opportunity to experiment with different approaches, to optimize the parameters of a particular intercession, or decide that the simulated outcome does not warrant the hazards and liabilities of intervention.

Progress—Computer-Aided Surgical Simulation (CASS) is a computer-based system whose antecedent was Computer-Aided Design (CAD), now widely applied in engineering. A similar approach provides the surgeon with a computer graphics display of the patient's anatomy, on which a tentative orthopaedic procedure can be implemented. Representations of the patient's movement patterns in the computer database are altered by the simulated intervention, and the computer displays the effect on the patient's posture, mobility, joint range-of-motion, etc. The surgeon is then free to alter and optimize the procedure until satisfied or perhaps abandon it, all before actual surgical intervention takes place.

Preliminary Results—The project is subdivided into four tasks: mobility analysis, patient-specific anatomical representation, individual muscle activity determination, and surgeon/computer interfacing.

Mobility Analysis. The Selspot TRACK systems at the Massachusetts Institute of Technology and Massachusetts General Hospital have been enhanced and applied in several relevant studies. Accurate and detailed knowledge of the instantaneous axes of rotation of conjugate body segments are essential to confident calculation of movement dynamics. A definitive study of alternate kinematic methods for calculating the instantaneous axes of the segmental joints was conducted using TRACK data from the human ankle, knee, and hip and, for evaluation of experimental accuracy, from a me-

chanical pendulum. The finite displacement method was shown to be superior. A novel computer display of human movement kinematics, employing solid body segments rather than the typical stick figures and implementing the orientation data from the TRACK system, was demonstrated.

An automatic calibration scheme to compensate for the inherent optical and transducer nonlinearities of Selspot cameras was developed. Improvements were achieved in noise-reduction of kinematic data. A definitive study on the frequency content of gait with implications for the required bandwidth of gait analysis systems was published.

The pressure-sensing instrumented hip prosthesis has been in place now for more than two years and is performing superbly both for the subject's benefit and as a data source. The new information is challenging the traditional understanding of synovial joint mechanics and of muscular action during normal movements. It will profoundly affect orthopaedic surgical practice and rehabilitation following all kinds of major hip surgery.

Patient-Specific Anatomical Representation. The use of computer tomographic (CT) and magnetic resonance imaging (MRI) scan data to generate patient-specific computer-driven color graphic displays of anatomy were advanced both by the development of new software and by the acquisition and networking of new computer hardware. The emphasis is on the automatic extraction via pattern recognition of anatomical contours from the cross-sectional slices produced by computer tomography, the assembly of such two-dimensional information into three-dimensional solid objects for computer display and animation, and on the developments of compact, effective means for the storage and retrieval of great masses of such data.

Surgeon/Computer Interfacing. To be employed effectively by, and accepted by, the medical profession, computer-aided surgical simulation must employ and exploit, in a natural fashion, the inherent knowledge and skills of the orthopaedic surgeon without imposing new additional training burdens. To assess the effectiveness of the anatomical displays, to explore

how best to control simulated surgical intervention, and to evaluate the surgeon's interpretation of the mobility changes brought about by the simulated surgery, a case study of inter-trochanteric osteotomy is under way.

In osteotomy, the surgeon's goal is to deliberately sever the femur, remove a slice or wedge of bone, and reorient the femoral compo-

nents three-dimensionally so as to put an area of normal cartilage in the load-bearing region, moving the damaged cartilage to an unloaded area. In so realigning the joint, however, the surgeon must continue to satisfy the physiological range of motion of the joint and must not interfere with normal gait patterns.

Upper Extremity Control Utilizing Functional Neuromuscular Stimulation (FNS)_____

P. Hunter Peckham, Ph.D., and Michael W. Keith, M.D.

Case Western-Reserve University, Cleveland, OH 44109

Sponsor: *National Institute of Handicapped Research*

Purpose—The purpose of this project is to evaluate the performance of a functional neuromuscular stimulation neural prosthesis in paralyzed human subjects for restoration of hand function.

Progress—Since 1978, we have evaluated 26 subjects who have sustained complete traumatic spinal cord injury at the C5 or C6 level. Paralyzed muscles are implanted with chronically indwelling percutaneous electrodes for control of lateral prehension-release and palmar prehension-release. Control is proportional and is provided by a volitional command of the subject, usually via the contralateral shoulder.

Functional assessment of clinical function is accomplished through a four-part testing protocol consisting of sensory evaluation, range of motion, manual muscle testing and muscle excitability, and functional evaluation. The last component of functional evaluation incorporates the Jebsen Hand Test (JHT), performance of isolated basic tasks, performance of coordinated tasks, and performance of integrated tasks.

The majority of testing is with nine subjects who are presently most active in our program and who are provided both grasp patterns. Examples of the various tasks demonstrated by the subjects are: 1) passive grasp (because the system does not necessarily have to be active and the user may wish to accomplish certain tasks without active grasp); 2) active grasp of utensils, books, writing instruments,

telephone, cups, etc.; 3) integrated tasks such as pouring, washing, diskette handling, brushing teeth; and 4) advanced tasks such as threading a needle, self-catheterization.

Preliminary Results—Most functional activities required the use of either a passive orthosis (PO) or the neuroprosthesis (NP). For example, feeding with utensils or writing could be accomplished with either the PO or NP. Feeding finger foods and drinking required NP usage. The most dramatic difference was in performance of transition tasks involving grasp, pickup and position, and release. A fork, pen, diskette, napkin, small book, and phone receiver were tested. All tasks required the NP in all subjects with the exception of the napkin, which 9 of 9 could accomplish passively, and the phone receiver, which 1 of 9 could accomplish passively. Because most hand tasks are of a transition nature, we interpret this aspect of performance as significant.

The results of these tests highlighted certain deficiencies in our present program that form the focus of future clinical effort. Goals include improving our training program to provide the subject with better planning strategy and providing smoother means for making transitions between grasping patterns.

We also have begun to apply the hand control technique to stroke/head-injury subjects. To date, one subject has been entered into the project. We have demonstrated qualitatively that flexor spasticity is reduced with short peri-

ods of stimulation, enabling us to provide full hand opening with FNS. Voluntary control of grasp, albeit abnormal mass patterns, is possible in the subject. Thus, at this early stage we

are focusing activity on reducing flexor spasticity to enable release functions through functional neuromuscular stimulation.

Nerve-Bundle Conduction Velocity Distributions: Clinical and Research Applications

Leslie Dorfman, M.D., and Kenneth Cummins, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Measurement of nerve conduction velocity (CV) is an important element in the electrophysiological evaluation of patients with suspected neuromuscular disorders. Conventional methods of determining nerve CV focus predominantly or exclusively on the velocity of the fastest-conducting (largest diameter) fibers in the nerve bundle. The properties of slower-conducting fibers, which constitute the majority of elements in the nerve bundle, are traditionally assessed only indirectly, or not at all.

The capability to estimate the conduction velocities of the various classes of nerve fibers composing the nerve bundle may be expected to enhance the sensitivity and specificity of neuromuscular electrodiagnosis, to improve the functional assessment of injured nerves, and to facilitate the quantitative evaluation of therapies for nerve diseases and injuries.

Progress—We developed a computer-based method for estimating the distribution of conduction velocities (DCV) in the subpopulation of large myelinated fibers composing human peripheral nerves. The method operates on surface-recorded compound nerve action potentials and is distinguished by its generality and its suitability for clinical implementation in the electroneuromyography laboratory.

Preliminary Results—Seven journal articles and one book have been published. Clinical

trials were set in motion, and the transition into regular clinical use was set under way at Stanford and at several other laboratories. DCV analysis was applied to the study of experimental nerve repair and regeneration. Discussions were conducted regarding commercial distribution of this technology.

Future Plans—Our hypotheses are: 1) that ongoing clinical trials of DCV analysis will confirm its diagnostic superiority to conventional measures of nerve CV; 2) that DCV analysis will yield insights into the pathophysiology of neuromuscular disorders and nerve injuries; and 3) that DCV analysis may be implemented on existing electroneuromyographic equipment, so as to be more widely available for evaluating patients with neuromuscular disabilities.

Toward this end, DCV analysis has been and continues to be applied in normal individuals, and in patients with diabetic neuropathy, nerve injury, amyotrophic lateral sclerosis, multiple sclerosis, and other conditions. The DCV findings in these individuals are compared and contrasted with those from conventional nerve CV measurements. Different methods of DCV analysis have been compared in normal individuals and in patients. DCV analysis has been implemented on one commercial electroneuromyograph, and a second implementation is under consideration.

Psychiatric Symptoms and the Functional Capacity to Work

Robert P. Liberman, M.D.; H. Keith Massel, Ph.D.; Jim Mintz, Ph.D.

Brentwood Division of West Los Angeles, Veterans Administration Medical Center, Los Angeles, CA 90073

Sponsor: *Social Security Administration*

Purpose—The purpose of the present study is to develop and empirically validate an operationalized psychiatric and behavioral assessment protocol to determine vocational capacity in psychiatrically impaired individuals. This is a 3-year project to establish criteria for determining qualifications for Social Security disability payments.

There are two major components of the project: psychiatric symptomatology and a functional assessment of vocational ability. All patients are given a psychiatric evaluation, consisting of structured interviews for determining diagnoses and current levels of symptomatology, before beginning the functional assessment phase of the protocol. Levels of symptomatology are also assessed throughout the functional assessment phase. Following this evaluation, psychiatric patients are randomly assigned to either a 3-day or 3-week assessment of their vocational abilities.

Progress—The functional assessments were conducted in a sheltered workshop setting on the grounds of the West Los Angeles Veterans Administration Medical Center. Subjects were assigned to work on four different tasks during the assessment period. These tasks (i.e., folding and packaging hand-towels; filing index cards; assembling electronic circuits; and assembling the flush mechanism for toilet tanks) assessed a variety of job-related skills. A wide range of measures were collected in this setting, including productivity rate, quality of work, attendance, punctuality, acceptability of appearance, ability to work independently, ability to follow instructions, ability to solve problems in cooperation with others, and interactions with peers. Most of these measures were taken

under conditions of both high and low demand.

Preliminary Results—Subjects were divided into four groups for analytic purposes: 1) psychotic—on disability; 2) psychotic—not on disability; 3) nonpsychotic—on disability; and 4) nonpsychotic—not on disability. At this point, 130 subjects have begun the functional assessment phase of the project. Of the 77 subjects assigned to the 3-day assessment, 62 (80.5 percent) completed at least 80 percent of their assigned task assessments. Of the 53 subjects assigned to the 3-week assessment, 32 (60.4 percent) completed at least 80 percent of their assigned task assessments.

These data are important with this population, as absentee rates frequently rise dramatically with symptom exacerbation. Subjects in the psychotic-disabled group have shown the least tolerance for the work setting, dropping out of the study at much higher rates than subjects in the other groups. Subjects in this group also perform more poorly on measures of work performance than those in the other groups.

Future Plans—The protocol of the study calls for 300 subjects, 170 of whom have yet to participate in the project. After all the data have been collected, multivariate analyses will be conducted to determine differences between the groups on psychiatric symptomatology, work performance, the ability to tolerate stress in the work setting, and/or historical variables. A work performance index will be developed as a standard for determining vocational ability. The relationship between psychiatric symptomatology and the functional ability to work will be clarified to a large extent by the results of this study.

Development and Evaluation of Dynamic Pedobarograph (DPBG) System for Clinical Use

D. W. Harrison, M.Sc., and E. G. Anderson, F.R.C.S.

Bioengineering Unit, University of Strathclyde, Glasgow G4 0NW Scotland and Orthopaedic Department, Western Infirmary, Glasgow, Scotland

Sponsor: *Scottish Home and Health Department*

Progress—The Department of Medical Physics at the Royal Hallamshire Hospital in Sheffield has developed a system for measuring and displaying dynamic pressures acting between the foot and the floor. The equipment is based on the pedobarograph developed by Chodera of Roehampton and consists of a piece of thick glass illuminated at two opposite edges by fluorescent strip lights. A thin sheet of opaque reflective plastic covers the top surface of the glass. As the subject stands on the plastic, the pressure generated between it and the glass breaks down the total internal reflection of light within the glass. When viewed from below, a variable light image of the foot is observed, the intensity of which is proportional to the magnitude of pressure. The image is recorded by a monochrome television camera and can subsequently be presented as images of pressure distribution.

Future Plans—To justify the provision of a fairly expensive piece of equipment in the orthopaedic clinic, a number of questions must be answered. The project aim, therefore, is first to determine whether the information that is obtained is reliable. It is well known that the response characteristics of the plastic will affect data produced from dynamic measurements. To

compensate, the total vertical load applied is correlated with the pressure readings and the areas associated with these pressures. It is intended to perform a series of closely controlled physical tests in order to validate the compensation procedures. Pressure measurements obtained from a walking subject will vary significantly depending on body movements rather than foot deformities. A record of the pattern of body movements will be obtained using two video camera recording systems viewing from the front and the side.

Secondly, we intend to determine if the information is of clinical use to the orthopaedic surgeon. Initially, a variety of data presentation techniques will be used to determine which provides the most useful information. A comparison of the diagnosis from DPBG results will be made with those obtained from other forms of data presentation currently used in the clinic (X-rays, patient examination) in order to assess usefulness of the pedobarograph in providing a more accurate diagnosis.

Finally, the DPBG will be used as a preoperative and postoperative monitor of patients undergoing foot surgery. Initially, we intend to concentrate on *Hallux Valgus*, *Hallux Rigidus* and Claw Toes patients.

VI. Biomechanics

A. Joint Studies

1. General

Biomechanical Studies of Bones and Joints

Sathya V. Hanagud, Ph.D.; Robin DeAndrade, M.D.; R. G. Clinton, Ph.D.
Veterans Administration Medical Center, Decatur, GA 30033

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—This project was a pilot study to collect data for further study of the biomechanics of bones and joints. Specifically, this study investigated the instantaneous changes in the dynamic or vibration response of knee joints. It appears that in traumatic injury or degenerative joint disease the dynamic response of the knee is different from that of damaged knees.

Progress—This study developed specialized instrumentation to measure the dynamic response. The instrumentation consists of an accelerometer to measure discontinuities in the movement of the joint and an acoustic emission pick-up to measure the resonance of the bone. Preliminary data indicated that the accelerometer readings were adversely affected by the soft tissue around the bone.

The Antagonist Muscle and Its Role in Maintaining Joint Stability

M. Solomonow, Ph.D.; R. Chuinard, M.D.; R. D'Ambrosia, M.D.; H. Shoji, M.D.; R. Baratta, M.Sc.
Bioengineering Laboratory, Department of Orthopaedic Surgery, Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: *LSU Bioengineering Foundation*

Progress—The previous phase of this study clearly indicated that the elbow antagonist muscle is active at various levels during isometric contraction. The current phase quantified the activity level and showed that the antagonist activity regulates the torque about the joint in such a manner that it compensates for the effect of the gravity vector, force level of the agonist, joint angle, and variations in the lever arm formed by the muscle tendon insertion in the bone. The net effect of the antago-

nist activity is to maintain joint stability, regulating the torque about the joint in the face of external and internal disturbances.

A significant new finding shows that mechanoreceptors are found in the ligaments, and upon ligament deformation they activate the antagonist muscle in a fast and direct reflex arc so that joint ligament overloading causes increased activity in the antagonist to assist in negotiating with the overload.

2. Lower Limb

Pathokinesiology of Anterior-Cruciate-Ligament Deficiency

Richard Shiavi, Ph.D.

Veterans Administration Medical Center, Nashville, TN 37203

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The objective of this project was to investigate the deviations from normal kinematics and muscle function in knees with ruptured anterior cruciate ligaments. Measurements were made using six-degree-of-freedom goniometry and electromyography during walking and pivoting.

Progress—The knee kinematics of eight individuals with uninjured knees and of seven individuals with injured knees were investigated. The kinematics were quantitated using helical motion analysis. The results of the helical motion analysis revealed clearly that the knee is definitely neither a hinge nor a planar joint. It is a dynamic joint whose kinematic behavior changes over the stride. A stationary joint center has been assumed in many biomechanical models and the mechanics are sensitive to its location. Thus, more sophisticated models are necessary for more than a general approximation to knee joint function.

The results also quantitatively define the changes in kinematics that occur from the loss of the anterior cruciate ligament. These changes are significant. Ligamentous loss results in more adduction and external rotation during certain periods of the stride. Also, the

range of translation of the tibia in the medial/lateral direction is reduced and its mean translation is more medial.

The study of EMG patterns in muscles acting around the knee joint reveals that individuals with injured knees have deviations in EMG linear envelopes with respect to the normal population. The most significant difference during walking is that the rectus femoris no longer has peak activity during the swing-to-stance transition period. During pivoting the most significant difference is that in the gastrocnemius the amplitudes of the major and minor phases of activity are switched. Unusual phasing of the peak activity in certain muscles is consistent throughout the patient population. Increased activity of otherwise quiescent muscles during specific intervals of the gait cycle can most likely be related to the absence of the anterior cruciate ligament and the support it would normally afford.

Future Plans—It is planned to continue this study in order to increase the size of the database. With a sufficiently large database, the effects that corrective procedures and joint prostheses have on knee kinematics and muscle function will be studied.

Development of Diagnostic and Therapeutic Procedure for Anterior-Cruciate-Ligament-Deficient Knees

M. Solomonow, Ph.D., and R. D'Ambrosia, M.D.

Bioengineering Laboratory, Department of Orthopaedic Surgery, Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: *LSU Bioengineering Foundation*

Progress—A procedure was developed in which electromyograms (EMGs) of the quadriceps and

hamstrings were collected during knee extension at maximal effort on the Cybex II system

at quasi-isometric speeds of 10 degrees per second.

It was shown that patients with anterior-cruciate-ligament-deficient knees underwent full or partial torque failure about 37 to 46 degrees of knee flexion angle with simultaneous EMG reduction from the quadriceps and EMG

increase from the hamstrings.

Patients with substantial muscle exercise therapy post-injury did not demonstrate failure, although EMG patterns were similar.

The evaluation system is undergoing modification for permanent installation in the Sport and Knee Clinic for routine use.

Computer Simulation of Knee Joint Mechanics

Felix E. Zajac, Ph.D.; Gary Yamaguchi, M.S.; Melissa Hoy, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Computer models of human motion (e.g., gait, jumping, cycling, etc.) require not only models of muscle and musculoskeletal geometry, but also models of the joints. Current joint models that accurately reflect knee behavior are highly complex, making them unsuitable for real-time whole-body dynamic simulations of motion, because the knee modeling task itself generally requires excessive computation.

The goals of this study are to determine the principal flexor/extensor mechanisms of the knee and to develop a computationally efficient knee joint model that can be incorporated in our overall dynamic system model of the lower extremity. Our efforts to develop and use such a model include the investigation of real-time computer animation as a clinical research tool. We envision realistic animation as such to be an informative and easily interpreted display of calculated results.

Real-time capability extends the usefulness of this display even further, because the effect of adjusting model parameters is evident immediately. For example, such a model may be used to explore the feasibility of lower-limb functional electrical stimulation (FES) systems on a patient-by-patient basis before surgery is actually performed.

Development of lower extremity musculoskeletal computer models of mammalian movement requires understanding of joint mechanics. In typical simulations of human gait, posture, and jumping, the knee joint is treated as a simple, two-dimensional pin joint. Yet it has long been known that the knee acts in a much

more complicated fashion. For example, numerous reports describe the contributions of articular surface geometry, movement of the instantaneous axis of tibial-femoral joint rotation, patellar mechanics, and so on. Highly detailed computational models have therefore been developed that take some of these factors into account, enabling researchers to predict joint behavior given a specific set of conditions. Although some other joints behave similarly to pin joints, these and other findings indicate that the knee does not and that it should be described more accurately due to its major influence on human mobility.

Progress—Thus far, with our musculotendon model, we have used combinations of simple mechanical elements (springs, dashpots, etc.) to form a system that behaves approximately like that of the living tissue. Such a model is needed for the knee joint as well, in order to reflect the effects of joint geometry and the mechanical levering action of the patella, and to determine the relative influence of various other joint phenomena on whole-body motions.

A minimal set of elements composed of idealized strings, rods, and cams is used to model the ligaments and tendons, the patella, and the articular surfaces of the femur and tibia, respectively. A two-dimensional model is formulated to allow independent specification of contact surface geometry, location, and movement of the instant center of joint rotation as a function of knee flexion angle, patellar and patellar ligament lengths, and initial orienta-

tions. Geometric and motion constraints are imposed to prohibit unrealistic configurations and motions, such as a tendon passing through the surface of the bone. Using this model with these constraints will enable us to emulate published experimental data and thus to determine, in essence, the mechanical operations of the joint.

Implementation of the model on a digital computer is nearly complete. Ongoing efforts are concentrating on determining realistic joint specifications and input parameters.

Future Plans—Future plans are to expand the joint model in order to explore the influence of patellar geometry and the effects of tendon and ligament elasticity, friction, and external forces. Once a working model is developed, we will incorporate it into our model of the lower extremity. We then intend to animate our real-time computer simulations of motion in order to evaluate limb control and coordination schemes, prostheses, and external supporting structures specific to FES patients.

Comprehensive, Quantitative, Predictive Model of the Human Knee Joint

Robert W. Mann, Sc.D.

Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *National Science Foundation*

Purpose—The knee is the largest, most complex, and most frequently injured of the synovial joints in the human body. The knee is subject to high complex loading, especially in single leg support, in athletics and in unexpected falls, and is susceptible to externally induced trauma due to the absence of thick, soft surrounding tissue. Knee injuries frequently culminate in permanent debilitation and may lead to osteoarthritis and the need for consequent replacement by artificially implanted joints. Prevention and treatment of injuries could be improved by better knowledge of the kinematics and dynamics of the normal and pathological knee, by better defining the contributions of the passive constraints—the cartilage surfaces, menisci, and ligaments—and by better understanding of the roles of the active constraints—the 15 muscles that act across the knee joint, 12 of which are biarticular with either the hip or the ankle.

This project is developing a comprehensive, mathematically expressed, computer-manipulable model of the human knee joint with which to calculate the kinematics and dynamics of the normal knee. Then, following adequate verification, we will employ the model to simulate the consequence of specific losses observed in the pathological knee. This model is expected to contribute to a better understanding of preven-

tive and treatment modalities.

The end-stage treatment of total replacement prostheses is yet to be as successful and widely adopted as those of the total hip replacement prosthesis. The understanding of the normal and pathological knee derived from the model is also expected to contribute to the specifications for improved total knee replacement prosthesis.

Progress—The mathematical model will be verified in part by comparison with unique *in vivo* data on the kinematics of the human knee joint acquired using the MIT TRACK movement analysis system. During acute experiments, the TRACK light-emitting-diode arrays were mounted on bone pins inserted into the femur and tibia bones of a consenting volunteer. Preliminary reduction of the data disclosed distinctly different patterns of motion in the loaded and unloaded joints. During the stance phase of gait, the motion appears dominated by the bony geometry and is definitely nonplanar. In voluntary flexion-extension of the unloaded knee, different trajectories occur in flexion versus extension, the articular surfaces do not appear to be in contact, and the motion is essentially planar. These data refute commonly accepted planar linkage models of the knee joint that characterize the role of the

anterior and posterior cruciate ligaments as a "four-bar linkage."

More refined processing of this unique kinematic data set has included a bachelor's thesis that evaluated different filtering and smoothing approaches, the adoption of Woltring's quintic-spline-smoothing approach, and the adaptation of this scheme to a 32-bit computer with a large virtual memory so as not to require sectoring of the data set.

The geometric mapping of the knee articular surface geometries and that of the menisci will employ an ultrasonic technique developed earlier in the hip investigation. A new ultrasonics scanner that can operate in spherical, cylindrical, or Cartesian coordinates has been designed and fabricated in the laboratory.

The mechanical properties of the ligaments for the model must go beyond the extant literature, which is concerned primarily with failure testing. The dynamic properties of bone-ligament-bone specimens were examined over the load range of interests to determine force relax-

ation as functions of initial load, initial strain rate, and after cyclical activity at several physiological frequencies.

Techniques have been developed and applied for using the TRACK system to establish and record the geometry of ligament and muscle insertions and origins. Dissection and measurement of the first human lower extremities are under way. To provide an independent data file on the muscle and ligament origins and insertions, the same leg has already been scanned with both computer-tomographic and magnetic resonance imaging machines.

Future Plans—In the future, we will compare the geometry from the reconstructed scan data with the TRACK physical measurements to test the feasibility of a noninvasive method for establishing specific muscular skeletal data for incorporation in future knee models based on different cadaver extremities. This technique may also prove clinically useful in planning and executing orthopaedic procedures.

B. Spine

Trunk Analysis System

L. Donald Gilmore, A.B.E.E.; Viktor R. Tiegermann, Ph.D.; Serge H. Roy, M.S.P.T.
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Purpose—In 1984, we began to explore the possibility of using our median frequency technique, along with measurements of conduction velocity, to assess the performance and interaction of the muscles in the trunk. One goal of this research is to develop a reliable screening method for distinguishing between the performance of trunk muscles in individuals with or without back disorders. To ensure accurate assessment of back performance, many individual muscle groups must be monitored.

Progress—A special restraining device that reliably stabilizes the trunk was designed to

assure that the muscle activity observed is actually associated with the flexion and extension torques being monitored. Considerable effort was made to design the restraint apparatus so that the individual's pelvis could be immobilized for at least an hour without discomfort.

The device is constructed from a commercially available hexagonal tubing system used in many hospitals. This allows the apparatus to be tailored to a large variety of subjects and postures. Specially contoured adjustable front and rear restraining pads hold the subject securely at the hip level. The torque generated during an isometric contraction of the back

muscles is measured with a nylon harness positioned across the shoulder region of the back. Sensitive load cells attached to this harness measure the forces produced as the back muscles contract.

A visual display unit, positioned at eye level in front of the subject, supplies a percentage of the maximum voluntary force that the subject can generate. The percentage of maximal force displayed to the subject can be set for

low, medium, or high levels of muscle contraction to measure the back muscles under different loading conditions. This feedback display is necessary to help the subject maintain an acceptably constant force output. The force information, together with myoelectric signals detected from an array of surface electrodes attached to the back muscles, is stored and processed using a small computer.

Mechanisms of Cervical Spine Injuries

Manohar Panjabi, Ph.D, Dr. Tech.; Richard Pelker, M.D., Ph.D.; Joanne Duranceau, M.S.
Department of Orthopaedics and Rehabilitation, Yale Medical School, New Haven, CT 06510
Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to produce clinically relevant instabilities in the cervical spine specimens under controlled high speed trauma. Three-dimensional instability measurements are made before and after the trauma. The injuries produced are documented by X-rays and CT scans. During the trauma production, complete load vector applied to the specimen is recorded by a computer while the 16 millimeter movie monitors the deformation pattern. This is done at the rate of 3,000 frames per second. The main goal of the project is to relate the roentgenographic appearance of the fractures with its quantitative three-dimensional instability.

Progress—All the equipment needed for the trauma production and recording has been constructed and is functioning. It consists of the trauma-producing apparatus, multi-dimensional load cell, data recording computer system, and a 16 mm high speed movie. All the components are coordinated by a control unit. The three-dimensional stability measurement apparatus is also ready. Preliminary studies using canine spine specimens and a few human spine specimens of the cervical spine region have been completed.

Preliminary Results—Several animal and human spine specimens have been successfully tested through all the phases of the experiment. Compression-flexion loading has been studied. The maximum load vector for the cervical spine specimen (C4-5) was 3500 N of compression, 50 Nm of flexion moment and 500 N of shear force. The total duration of the load vector was about 10 ms. One of the most interesting results was the differential instability produced in the specimen for different degrees-of-freedom of movement. In other words, due to trauma there was a significant increase in the instability for axial rotation and flexion while the change in the lateral bending instability was minimal. This differentiated information concerning three-dimensional instability of an injured spine will be clinically helpful in designing optimum surgery and external support for a given fracture.

Future Plans—The preliminary studies using canine cervical spines will be continued. Thirty specimens will be traumatized in flexion-compression, extension-compression, and pure compression loadings. Immediately following the canine study, the human cervical spine study will be completed using the same protocol.

C. Human Locomotion and Gait Training

Gait Analysis By Use of an Instrumented Treadmill

Erik C. Jansen, M.D.; Tommy K. Larsen, M.D.; Christian G. Sorensen, M.D.

Biomechanical Laboratory T, Gentofte Hospital, University of Copenhagen, DK-2900 Hellerup, Denmark

Sponsor: *Outer Copenhagen Hospital Administration; Danish Medical Research Fund; Hafnia Insurance Ltd.*

Purpose—The instrument for gait analysis is a treadmill permitting an unlimited length of gait. The treadmill is constructed to perform continuous measurements of the ground reaction forces for each foot. The measurements are processed on a PDP 11/10 computer. The output is a series of information: force curves of each of the three-dimensional vectors of each foot, average curves of the forces, calculation of

ataxia, and calculation of the external work of each foot are computed. A typical gait analysis is based on 60 seconds of continuous gait. Studies of normal and pathologic gait have previously been published.

At present, studies of uphill and downhill walking are performed. The influence of total hip replacement on gait is investigated as well as different types of orthotics and prosthesis.

The Muscular Biomechanics of Human Posture

Felix E. Zajac, Ph.D. and Michael E. Gordon, M.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—Persons with paraplegia need to regain functional use of their legs. An essential prerequisite for this is the restoration of upright posture, as the maintenance of posture is fundamental to movement. The human body is naturally unstable in the standing position, and upright posture is sustained with the fine coordination of many muscles. An understanding of the biomechanics and muscular coordination of posture is requisite to designing functional electrical stimulation (FES) systems for paraplegics in regaining leg movement.

FES is potentially a useful method for restoring upright posture in paraplegics. For FES to be used effectively, we must know which muscles to stimulate and how they should be coordinated.

Experimental research on posture suggests that muscular coordination is simplified by the organization of muscles into groups, with muscles in each group working together as a muscular synergy. The experimental identification of synergies is limited, however, because experi-

ments are unable to discriminate between the activities of nearby muscles and are unable to monitor the function of deep muscles.

An engineering model can give much insight into the muscular biomechanics of upright posture. It is hypothesized that the muscles used in synergies are consistent with those used to maximally accelerate the body from a disturbed position toward the upright standing position.

Progress—An engineering model, based on the properties of the musculoskeletal system, has been developed. The body is represented as four rigid segments: foot, shank, thigh, and torso. The musculoskeletal system is modeled in detail, and 14 muscles of the ankle, knee, and hip are included. The muscles are represented by a generic dimensionless musculotendon model, and this is scaled to each muscle/tendon by the muscle strength, muscle fiber length, and tendon slack length.

The engineering model considers body posi-

tions from forward and backward swaying, with the knees fully extended and the feet flat on the ground. Optimization techniques are used to identify the functional significance of different muscles, their organization into synergies, and the body positions in which each synergy is effective. Additionally, optimization is used to determine quantitatively the significance of the various physical constraints, such as keeping the feet on the ground and keeping the knees fully extended.

The computer model has been developed and thoroughly tested. Preliminary results predict muscular synergies that are consistent with experimental work. Because muscles can only pull, and not push, the different muscular synergies are effective in only certain of the body positions.

For example, two synergies come into play in the lower limb: synergy I, using muscles on the front side of the body, and synergy II, using muscles on the back side of the body. Each syn-

ergy is used over a different range of shank and torso angles. The results identify the separate contribution of muscles such as soleus that have been neglected or grouped with other muscles in previous work. Also, the optimization results provide insight into the specific way in which posture is recovered. For example, should the upper body recover first, or should the leg? In general, it appears that the physical constraints severely restrict direct acceleration toward the upright position. Insufficient muscle strength does not seem to be a primary problem. The major difficulties are keeping the feet flat on the ground, due to the short length of the feet, and in keeping the knees in the fully extended position. Currently we are relaxing these constraints to investigate their effects on muscular synergies and the ability to accelerate toward the upright position. Additionally, the results of this work is being prepared for publication.

Effect of Shock-Absorbing Materials on Heel-Strike Forces

Tony A. Cutshall, M.S.; D. D. Moyle, Ph.D.; Edward W. Berg, M.D.

Bioengineering Alliance of South Carolina, Clemson University, Clemson, SC 29634; William Jennings Bryan Dorn VA Medical Center, Columbia, SC 29203

Sponsor: VA Rehabilitation Research and Development Service; Bioengineering Alliance of South Carolina

Purpose—Researchers have shown a correlation between degenerative joint disease and the ability of the musculoskeletal system to absorb shock. The purpose of this investigation was to develop a system capable of monitoring the force between the heel and the shoe and then to determine the effect of different shock-absorbing materials on these forces in hope of finding possible candidate materials that may aid the arthritic in combating pain and further joint degeneration.

Progress—The system that was developed consists of three components: a transducer heel-pad, a Cyber Systems MicroDAS data acquisition subsystem, and an IBM PC XT personal computer. The instrumented heel-pad was made of eight lead zirconate titanate piezoelectric transducers bonded to a sheet of conductive

silicone elastomer embedded in common RTV silicone rubber. Lead wires from each transducer were cabled to the MicroDAS, where analog signal conditioning was performed. Data acquisition control and data analysis were performed by the personal computer.

Fifteen healthy young adults, 10 male and 5 female, were studied. A series of 10 runs (a control run and 9 candidate material runs) was used for each subject. Relative measurements of force and impulse were taken during each run for all subjects. Significant improvements, as compared to the control, in force and impulse for each subject were calculated using Tukey's Honestly Significant Different Test, a conservative comparison between means. Comparisons between subjects were performed using the Kruskal-Wallis test and a modified conservative rank comparison procedure.

Statistical comparisons showed that there were no significant improvements in force ($H = 13.45$, $p > 0.143$) or impulse ($H = 14.13$, $p = 0.118$) for the female subjects. Similarly, there were no significant improvements in impulse for the male subjects ($H = 14.30$, $p > 0.112$).

However, significant reductions in the heel-strike forces of the male subjects were noted with four materials ($H = 38.65$, $p < 0.001$). In order of average rank, these were: Pelite, Frelonic, Firm Density Plastazote, and Viscolite.

Foot Interface Pressure Study

Frank L. Golbranson, M.D.; Roy W. Wirta, B.S.M.E.; Eric J. Kuncir, M.S.B.E.
Veterans Administration Medical Center, San Diego, CA 92161

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This study focused on the clinical treatment of the insensate foot and means to protect the plantar surface having or not having ulcerations. The purposes of this multi-fold project included the following: 1) investigate the suitability of various commercially available, heat-moldable plastic foam materials to redistribute plantar pressures; 2) determine relevant physical properties of plastic foam materials; 3) map vibratory perception thresholds on the foot and leg among diabetic patients; and 4) attempt to determine an at-risk boundary among diabetic patients.

Progress—The load-bearing characteristics of selected polyethylene foams were determined and described in terms of structural and compression properties. Based on this analysis, it was concluded that for the not-at-risk patients who do not require a high degree of plantar pressure redistribution, unmolded, small-cell, foamed polyethylene insoles are satisfactory. Further, issuing four sets for daily change allows insoles to recover from temporary compression set. For "at risk" patients without ulcers, molded bilaminate insoles were issued for maximum pressure relief. The "at risk" patients with noninfected ulcers, on the other hand, required two stage treatment: total con-

tact cast during ulcer healing followed by thick heat-molded insoles and sandals while scar tissue matures. Vibratory perception data measured with a Bio-Thesiometer (Bio-Medical Instruments Co., Newbury, OH) were gathered on 167 patients presenting at the Diabetic Foot Clinic. Of this group, data of 90 individuals were deemed unusable in an analysis of vibratory sensibility for reasons of nonreliability or insensitivity unrelated to diabetes (i.e., secondary to alcoholism or chronic anemia). A statistical analysis of the 77 satisfactory data sets revealed a strong correlation between age and history of plantar ulcer development to vibratory threshold levels. A weaker relation was noted for years since onset of diabetes. Established was an 83 percent chance of predicting at-risk of ulcer development based on the values of selected vibratory thresholds.

A paper entitled "The Load Bearing Characteristics of Polyethylene Foam: An Examination of Structural and Compression Properties," was submitted for publication. This paper is an overview of those properties of cellular foams that may be useful in the determination of the function of a particular material in load-bearing applications.

The project was completed and a final report has been prepared.

Swing-Through Crutch Ambulation by Persons with Paraplegia

Dudley S. Childress, Ph.D., and Robert van Vorhis, M.S.

Rehabilitation Engineering Program, Northwestern University, Chicago, IL 60611

Sponsor: *National Institute of Handicapped Research*

Purpose—The objectives of this study were to establish the aspects of crutch-assisted swing-through gait of persons with paraplegia that are energy intensive and to determine whether ways might be achieved to reduce energy expenditures. The hypothesis was that efficient crutch ambulation is feasible for the paraplegic ambulator.

Crutch walking gives increased mobility to a person with paraplegia. Curbs, stairs, or rough terrain do not limit access. Crutches take up less space than wheelchairs and can be used easily in unmodified offices and homes. They permit more easy access to public transportation than wheelchairs do. Crutches put the user at eye level with peers and may increase a person's morale and physical well being. On the other hand, the types of crutches typically used require high levels of energy. They increase risk of falling. And a wheelchair is capable of faster speeds at much higher efficiency on smooth surfaces. The ambulator must compromise with either system.

Establishing a technique for efficient swing-through crutch ambulation will provide the paraplegic ambulator with another option for gait modality. We believe it will be a long time before functional neuromuscular stimulation (FNS) systems can adequately provide dynamic postural control (balance) during ambulation. Therefore, even with sophisticated bipedal stimulation systems, crutches will likely be used. The gait modality of efficient and fast swing-through crutch ambulation would complement a bipedal FNS system as well as provide an alternative to wheelchair ambulation.

This study expands a preliminary investigation performed at this laboratory entitled "Kinematic and Pendular Aspects of Swing-Through Paraplegic Crutch Ambulation" (J. S. Rovick, M.S. thesis, Northwestern University, 1982). Rovick examined the kinematics of swing-through paraplegic crutch gait and mod-

eled the gait with mathematical models that were based on physical principles. His work indicates three main areas of energy expenditure: 1) the energy required in stabilization of the joints (e.g., elbow and shoulder); 2) the energy lost in the muscular effort to elevate the body to allow the feet to clear the ground; and 3) the energy used to control the motion of the trunk. In this study, a major focus will be to try to eliminate the significant lifting of the trunk and legs to facilitate floor clearance during the swing phase. It is anticipated that by eliminating or reducing this expenditure of mechanical work there may also be reduction in the energy expenditure associated with control of the motion of the trunk. The plan is to utilize both crutch lengthening (via a rocker modification of the crutches) and leg shortening (via ankle control) as a means of facilitating ground clearance without energy-intensive lifting. The models of Rovick will be modified and used as conceptual design tools.

Evaluation of the normal and modified swing-through gait of subjects with paraplegia will be done by calculation of the mechanical work done during ambulation from the basic definition of mechanical work (the product of joint moments and joint velocity). The validity and sensitivity of this technique will be established. To obtain useful results in this study, it has been established that high-accuracy, high-sampling-rate positional data are required along with measurement of feet and crutches floor reaction.

Progress—The collection of data during clinical walking trials has been delayed during the development of a motion analysis facility based on the CODA-3 Movement Monitoring Instrument and utilizing two biomechanics platforms. This development work will be completed soon.

It is hoped that the feasibility of reducing the energy demand of swing-through crutch

ambulation by persons with paraplegia can be established and that a technique with the clini-

cal potential of achieving ambulation in persons with paraplegic can be realized.

Weight Transfer Using Biofeedback

Harold M. Sterling, M.D. and Donald R. McNeal, Ph.D.
Veterans Administration Medical Center, Loma Linda, CA 92357
Sponsor: VA Rehabilitation Research and Development Service

Purpose—This study was designed to characterize changes in gait and balance after a 3- to 4-week rehabilitation program in an inpatient control group of adult hemiplegic subjects and to compare these changes to those of a matched experimental group who receive specialized biofeedback balance retraining.

Progress—To date, 40 control subjects and 8 experimental subjects have participated in the study. Both groups received physical therapy for 1.5 hours daily, 5 days a week. While the control group received standard therapy, the experimental group received an hour of biofeedback retraining. Biofeedback provided an immediate video display of the relative distribution of body weight carried by each limb during standing. Measures of gait and balance were collected before and after the therapy program. Footswitch and forceplate data were used to quantify the change. Multivariate analyses (Hotelling's T^2) were used to evaluate the pretest-posttest differences in the control group. Multivariate analysis of variance will be used to

evaluate differences between control and experimental groups when data collection has been completed with the experimental group.

Preliminary Results—In the control group, dependent measures of the total gait cycle (e.g., velocity, gait cycle time) changed significantly ($p = 0.004$), whereas dependent measures of the gait cycle segments (e.g., single- and double-limb stance times), symmetry (swing time ratio between limbs), and support through an instrumented force cane, did not change ($p = 0.05$). Although dependent measures of balance (e.g., center of pressure variability and deviation) changed significantly ($p = 0.01$), this was due to increased stability on the less-affected limb. The current hypothesis under investigation postulates that biofeedback training will achieve greater symmetry in balance and gait than was seen in the control group. Preliminary results indicate that following biofeedback training, subjects do learn to bear weight more evenly in static standing and when attempting even weightbearing.

Gait, Balance and Symmetry in Hemiplegia: An Analysis With and Without Biofeedback Retraining

E. R. Gardner, M.S., P.T.; C. J. Winstein, M.S., P.T.; D. R. McNeal, Ph.D.; J. Perry, M.D.
Rancho Los Amigos Rehabilitation Engineering Center, Pathokinesiology Laboratory, Downey, CA 90242
Sponsor: VA Rehabilitation Research and Development Service; National Institute of Handicapped Research

Purpose—Movement and balance deficits seen in the hemiplegic adult have been well documented, but few studies have reported the change that occurs in gait and balance following an intensive rehabilitation program. Furthermore, it is generally accepted that retraining balance and weight shifting ability will affect the quality of gait in this population.

This relationship has not been substantiated in the literature.

The present study was designed to characterize changes in gait and balance after a 3- to 4-week rehabilitation program in an inpatient control group of adult hemiplegic subjects and to compare these changes to those of a matched experimental group who receive specialized bio-

feedback balance retraining.

Progress—Forty control subjects (mean age, 53.6 years; mean time from onset, 7.1 weeks) and 20 experimental subjects (mean age, 51.5 years; mean time from onset, 7.7 weeks) participated in the study. The subjects were selected according to the following minimum criteria: 1) no outstanding medical complications other than the CVA; 2) long-range rehabilitation goal of ambulation; 3) ability to stand without external support for 30 seconds; and 4) consent to participate. Both groups received physical therapy for 1.5 hours daily, 5 days a week. While the control group received standard therapy, the experimental group received from 45 to 60 minutes of biofeedback retraining per day. Biofeedback provided an immediate video display of the relative distribution of body weight carried by each limb during standing. Measures of gait and balance were collected before and after the therapy program. Footswitch and force plate data were used to quantify the change. Multivariate analyses were used to evaluate pretest-posttest differences in the control group. Preliminary analysis of experimental group data is descriptive at the present time, although multivariate ANOVA is planned for group comparison.

Preliminary Results—Gait was analyzed in highly correlated clusters of dependent variables reflecting measures of the total gait cycle (velocity, gait cycle, stride length, cadence), the relative gait cycle components (single-limb and double-limb stance times), and gait symmetry (swing to swing, stance to stance, and stance to swing ratios). Results from the control group indicate that whereas dependent measures of the

total gait cycle changed significantly ($p = 0.035$), dependent measures of the relative gait cycle segments, symmetry, and support through an instrumented force cane did not change ($p > 0.05$). Although subjects were able to walk faster as a result of rehabilitation, interlimb coordination remained unchanged.

Balance was analyzed in highly correlated clusters of dependent variables reflecting measures of the position of the center of pressure (CP) in relation to the base of support (CP lateral and anterior-posterior), and stability in that position (variability/second lateral and anterior-posterior, mean deviation lateral and anterior-posterior). Results from the control group indicate that although dependent measures of stability changed significantly ($p = 0.0002$), position of the center of pressure remained shifted toward the uninvolved limb ($p > 0.05$). Following rehabilitation, subjects demonstrated improved stability on their less-affected limb.

The hypothesis under investigation suggests that biofeedback training will achieve greater symmetry in gait and balance than was seen in the control group. Preliminary results indicate that following biofeedback training, subjects do learn to bear weight evenly in static standing as well as when attempting even weight bearing. In contrast, gait symmetry remains unchanged as compared to that of the control group.

These preliminary findings suggest that with specific biofeedback training, hemiplegic adults are able to achieve improved static standing symmetry, but the results raise questions regarding the appropriate training techniques necessary to affect interlimb symmetry during locomotion.

A Modular Gait Analysis System

William V. James, F.R.C.S.; John F. Orr, Ph.D.; Trevor Huddleston, B.Sc.; David Weir, M.Sc.

Northern Ireland Rehabilitation Engineering Centre, Musgrave Park Hospital, Belfast BT9 7JB, Northern Ireland

Sponsor: *The Northern Ireland Department of Health*

Purpose—The aim of the project is to provide a modular, portable, low-cost gait analysis system suitable for clinical use. It is based on the Mus-

grave Park "Foot Pressure Profile Platform," which is a low-profile platform containing 512 load cells that gives information about discreet

areas of foot pressure. These cells provide data that are stored in a low-cost computer. Two such platforms provide information about stride length. The data provide a monitor display and also can be analyzed. Additionally, an electrogoniometer system has been produced, recording the movements of six joints, and the data have been integrated into the computer. This information provides an analysis of the gait cycle.

Progress—To date, in addition to the raw data,

Human Movement Monitoring System to Study Posture, Walking and Jumping

Felix Zajac, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—In order to assess a patient's musculoskeletal disabilities associated with posture and gait, it is necessary to record, simultaneously, the kinematic, electromyographic, and kinetic data from that patient.

The Selspot system, a three-dimensional monitoring system manufactured by Selcom Selective Electronic, Inc., is used to digitize and record traces of motion. It has proved to be a useful tool for recording experimental kinematics. However, the software supplied by Selcom for controlling the Selspot system took up the full resources of our PDP-11/34 computer, which meant that data collected from other sources during an experiment had to be recorded off-line on an analog tape recorder. Synchronizing that data with the Selspot data was difficult and increased experimental error by a significant amount.

In order to record kinetic, electromyographical, and kinematic data simultaneously with a single computing system, we needed to

the system provides an analysis of the hip, knee, and ankle movements, the center of pressure under the foot, and the foot pressure/time relationship. The system is undergoing trials at present, in order to review the type of information needed by clinicians and to assess its method of presentation. Because the system is modular, different clinicians can select modules that are applicable to their problem, and they can be provided with software suitable to their needs.

modify the Selspot software and the memory configuration of the computer.

Progress—Existing computer programs allowed us to collect and store 32 channels of kinetic and electromyographic data. By modifying the memory configuration of a Digital PDP-11/34 and the Selcom software, we were able to record kinematic and kinetic data with a single computer system.

Preliminary Results—Currently it is possible, with a single computing system, to record simultaneously the data from 20 peripheral channels and the Selspot system for a period of 5 seconds. We are in the process of writing programs that will initialize and start both systems with a minimum amount of input from the user. Steps are also being taken to allow the data to be displayed as it is collected, to confirm data acquisition.

D. Upper Limb Applications

Analysis of Hand Performance Patterns in Able-Bodied and Cerebral-Palsied Subjects

Don Malzahn, Ph.D.

Department of Industrial Engineering, Wichita State University, Rehabilitation Engineering Center, Wichita, KS 67208

Sponsor: *Cerebral Palsy Research Foundation of Kansas, Inc.*

Purpose—The objective of this research is two-fold: to develop standards of able-bodied hand performance patterns, and to develop task design and modification principles for neurologically impaired populations, based upon a comparison of these able-bodied standards.

Currently, no information has been published on the normal pattern of hand performance of industrial tasks. Expected differences between males and females and the difference between preferred and nonpreferred hands have been published for only a few selected manual tasks. If it is assumed that the man-made environment has been designed with at least an unconscious reference to normal ability, the comparison of the profile of a class of disabled individuals to able-bodied standards should indicate appropriate ways of accommodating to that environment.

Progress—Subjects for this study consisted of 92 able-bodied adults, 46 male and 46 female, and 47 clients of the Cerebral Palsy Research Foundation of Kansas (CPR).

The performance measurement system used was the Available Motions Inventory (AMI) test battery of 71 manual industrial tasks presented in an adjustable workstation. The test battery is repeated for each hand. Six major types of subtests within the AMI were used: switches, settings, rates, strength, assembly, and reach-reaction. Several of the tests are repeated in a variety of subject orientations.

Hand preference for each subject was empirically determined by averaging the performance scores for each hand separately. The hand with the higher score was labeled the superior hand. The one with the lower score was determined to be the inferior hand. Raw scores for

the superior hand of the able-bodied group were normalized (mean = 0.0, standard deviation = 1.0). Raw scores for each of the 71 subtests for the inferior hand of the able-bodied group were then converted using the mean and standard deviation of the able-bodied superior hand performance.

Gender, hand preference, and type were examined for the able-bodied group, and a three-way repeated measures analysis of variance was performed. Subtests were ordered from the easiest (reach-reaction) to the most difficult (assembly) based on the average score of all subjects and both hands.

Preliminary Results—The direction of interaction between gender and test type can be seen in strength, reach-reaction, and assembly tests. Males performed relatively better on strength and reach-reaction, and females were relatively better on assembly. The inferior hand is differentially affected by the assembly test.

In hand and similarity-and-difference tests, the degree of similarity between each of the 92 subjects' superior and inferior hands was examined. Tasks that were performed well by the superior hand were also performed well by the inferior hand.

While a majority of the subtests indicate a significant difference between the superior and inferior hands, several subtests indicate that the inferior hand actually performs better.

Results—Subtests within the AMI repeated in several positions indicate a significant interaction between hand and position. Pairwise comparison of cell means indicate that the superior and inferior hands performed at significantly different levels for all positions except side/

lower/horizontal (SLH—to the side, at a bench top, horizontal orientation). In the SLH position, the superior and inferior hands perform at essentially the same level. Furthermore, a comparison of means shows that in SLH and CLH, test activities performed to either side and directly in front of the individual on a horizontal plane, differed significantly from other positions in which the test modules were presented in a vertical position. Finally, in the CLH position, in front of the subject at a horizontal orientation, the hands demonstrate their greatest difference.

In comparison with the able-bodied group, the cerebral-palsied subjects are more alike on reach-reaction and strength tests, and more different on the assembly test. Generally this implies that the simpler the task, the more an individual with cerebral palsy will perform like an able-bodied person.

The general conclusion is that there is a strong relationship between the pattern of performance of the superior and inferior hands, but that disabled individuals' specific patterns are more pronounced than in the able-bodied population. The degree of association between superior and inferior hands can also be seen.

The average level of performance of the superior and inferior hands was also examined. It is evident that the average level of performance of one hand is a good predictor of the other. The disabled group could be classed as diplegic. The remaining group could be classed as hemiplegic in that the average level of the inferior hand is significantly lower than the trend established by the able-bodied population.

The difference between superior and inferior hand performance of the group with cerebral palsy was evaluated using a *paired-t* statistic. All subtests indicate that there is a significant difference between the functional level of each hand. The profile for the disabled group shows much less variability than does the able-bodied group. This is to be expected with a significant number of hemiplegic subjects in the disabled group.

These initial results indicate it is feasible to use the AMI database to develop general design principles for specific disability types. Research should be extended to include analysis of the position parameter for the disabled group. Other classes of disability should also be evaluated.

E. Other

Mathematical Models for Bone Inelasticity and Bone Damage

Dennis Carter, Ph.D. and John Kennedy, M.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The intent of this study is to establish mathematical models for the mechanical response of cortical bone in the domain of inelastic deformation. The focus is to develop a new constitutive theory that characterizes the inelastic behavior of bone as it experiences irreversible deformation due, at least in part, to the formation of microcracks and voids (collectively called "damage"). This theory, which would describe brittle modes of inelasticity, is

intended to serve as a counterpart to the theory of plasticity, which describes ductile modes of inelasticity in metals.

The potential significance of such a theory relates to the following: Stress-induced remodeling has important implications in the practice of orthopaedics, because many orthopaedic procedures alter the forces applied to the skeleton. The rapid growth of implant surgery in recent years has caused concern about how the altered

stress and corresponding damage fields in bone near the implant will influence the long-term success of the implant procedure.

Clinical investigations have shown that a reduction of *in vivo* skeletal loading results in loss of bone mass (bone atrophy), whereas increased skeletal loading causes a gain of bone mass (bone hypertrophy). Bone atrophy and hypertrophy are believed to be directly related to the change in stress field (and corresponding damage) within the bone. In addition, bones tested *in vitro* to failure under monotonic and cyclic loading are found to contain considerable microcrack and void densities in the region local to failure, suggesting that such damage is a primary cause for the loss of structural integrity in the bone. It is apparent, therefore, that it would be useful to generate mathematical models that might reliably predict stress, strain, and damage fields in order to predict bone loss or gain as well as to assess the structural integrity of the skeleton.

The approach selected employs techniques of continuum thermomechanics to develop a thermodynamically consistent constitutive

theory for characterizing bone inelasticity and bone damage. Characterization of the mechanical response in terms of thermodynamic potentials would provide an opportunity to study the interaction between the mechanical response and biochemical response of bone tissue.

Progress—A simple, one-dimensional, cumulative damage model has been developed using classical creep equations to model bone fracture. A three-dimensional extension of this model, incorporating a scalar damage variable, has also been constructed. Both such creep-based models are strictly mechanical models.

A general structure for thermodynamically based damage constitutive equations has been established. Specific functional forms for the thermodynamically based constitutive equations for bone have not yet been established. Moreover, an explicit mathematical representation of the coupling between the mechanical and biochemical responses of bone through the second law of thermodynamics has also not yet been established.

Bone Fatigue and Creep Damage

Dennis Carter, Ph.D.; William Caler, M.S.; Cheryl Gira, M.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The mechanical behavior of cortical bone under conditions of cyclic loading (fatigue) and static loading (creep) has not been well characterized. The intent of this study is to develop a mathematical model, based on creep and fatigue damage accumulation, which will predict bone fracture under various loading histories. Normal bone growth and turnover, osteoporosis due to bed rest, hypertrophy in response to exercise, and fatigue fracture are influenced by mechanical forces. The exact nature of the bone "adaptive" response is not known; however, researchers have demonstrated that static loads *in vivo* can cause either no change in bone mass, or bone resorption due to necrosis, while fatigue damage *in vivo* produces marked hypertrophy.

Our approach is to study a variety of simple loading histories and then use the principle of superposition to predict the bone response to combined loads. When subjected to high loads, or to low loads over a long time period, the material will accumulate damage and eventually break. The nature of the accumulated damage is different depending on the type of load. The damage can be observed by looking at the fracture surfaces using a scanning electron microscope (SEM).

Progress—Machined bone specimens have been tested under a variety of loading conditions. Constant loads have been applied in both tension and compression until specimen fracture (creep-fracture). Fatigue tests have been per-

formed in tension, compression, and combinations of tension and compression. The results have led to a mathematical model which attempts to predict time-to-fracture by summing creep (time-dependent) and fatigue (cycle-dependent) damage.

Preliminary Results—Tensile fatigue and com-

pressive fatigue results suggest that tensile cyclic loading creates primarily time-dependent damage, while compressive cyclic loading creates primarily cycle-dependent damage.

Future Plans—The next step is to use the results described to predict failure for combinations of cyclic tension and compression.

Mechanical Stress Influences on Cartilage Degeneration and Ossification

Dennis Carter, Ph.D.; David Fyhrie, Ph.D.; Tracy Orr, M.E.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Osteoarthritis, or degenerative joint disease, is a crippling disorder associated with aging. Virtually every individual who lives long enough will experience the degenerative changes in the cartilage at the joint surfaces that are associated with this condition.

Although it is widely acknowledged that mechanical stresses play a critical role in the pathogenesis of osteoarthritis, the mechanics associated with degenerative processes in cartilage have not been established.

We have developed a general theory for the mechanical regulation of biological processes in the chondro-osseous skeleton which is based on optimization of local strain energy transfer. The form of this theory is indistinguishable from one based on an optimization of fatigue damage accumulation in multiaxial loading states, yet is compatible with any proposed stress-induced stimulus (e.g., stress-generated potentials). This theory can be used to describe and predict the biological events associated with cartilage degeneration and ossification throughout life, beginning with the embryonic cartilage anlage.

We propose that biochemical processes of the chondro-osseous skeleton are driven to a major extent by the strain energy that is transferred (or dissipated) during intermittent mechanical loading. The ossification of cartilage will proceed based on the magnitudes of strain energy transfer rates (energy transferred per day). Cartilage degeneration and ossification will be slow in low-energy-transfer areas (e.g.,

all growth plates) and will be inhibited in areas of high, intermittent, compressive hydrostatic (dilatational) stress (e.g., articular cartilage and most growth plates). Once ossification occurs, the bone density and orientation will be modulated to provide an optimum level of strain-energy transfer rate at all sites, using the minimum amount of bone.

Progress—Four finite element models representing the proximal femur and hip joint have been generated, and more than 50 analyses with different loading and material properties are being conducted. The first model is a 2-D linear representation of the fetal cartilage anlage. The effect of intermittent daily loading on the cumulative strain energy transferred is simulated by superimposing the distributions of the stored strain energy imposed by a representative spectrum of loading conditions. The energy transfer rate is assumed to drive the process of ossification. The anlage material properties are successively changed to reflect mineralization as predicted by the contours of energy-transfer rate. In this manner, the entire growth and maturation of the femur at different stages of skeletal maturity are modeled.

The stress states and strain energy in the adult hip joint are further studied with a 2-D nonlinear-contact model of the joint and a linear 3-D idealized model of the femoral head.

Preliminary Results—The pattern of primary ossification and the formation of the diaphyseal

cortex were predicted by the models, as was the geometry of the primary ossification front. The growth plate location and geometry were predicted and shown to describe a contour of minimum energy-transfer rate. The developmental stage and location for the appearance of secondary ossification sites were predicted. The distribution of articular cartilage thickness and the sites of initial osteoarthritic changes in the

aged were also described.

Future Plans—Analyses are continuing under the expectation that we are developing a general theory for the role of mechanical energy in the control of the biology of chondro-osseous tissue. Applications of such a theory to normal and pathological skeletal physiology would have far reaching implications.

The Influence of Exercise on the Regulation of Bone Density

Dennis Carter, Ph.D., and Charles Steele, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Skeletal mass and bone density measurements of selected trabecular bone sites are often used to assess the condition of the skeletal system. The variety of body sizes and types makes the interpretation of these absolute numbers difficult. Attempts to normalize these variables with respect to physical size have not been and cannot be successful. Beyond body size and other hereditary influences, factors identified as regulating bone volume include activity level, exercise, sex, diet, race, and hormone levels.

Proper correlation between these variables and skeletal response is needed to identify the forces of remodeling and guide clinicians in the development of programs to prevent, reverse, or slow the loss of bone with aging. Early detection and prevention of osteoporosis requires a quantitative understanding of the environmental factors which influence bone metabolism. If we can predict densities for various activity levels and exercises, then we have a mechanism for early detection of osteoporosis. We also suggest that prevention may take the form of exercises tailored to promote and maintain high bone density throughout one's life.

The overwhelming body of clinical and experimental evidence suggests that for healthy young persons, activity level and certain types of exercise are the dominant factors in bone metabolism. Athletic activities which involve significant increases in joint loads increase bone mass in the heavily loaded bones. (the hu-

merus of the playing arm of 84 world-class athletes showed pronounced hypertrophy; cross-country runners were found to have a 20 percent greater calcaneal density than a nonexercising control population. On the opposing end of the loading spectrum, removal or reduction in the level of physical activity through immobilization or bedrest has consistently resulted in severe bone resorption.

However, numerous bedrest studies have included exercise protocols to test the hypothesis that forces on the body regulate skeletal mass, and none of these was successful in reducing the level of bone loss. That fact has caused some to question the role of exercise in the regulation of bone metabolism. We find no contradiction in the results, and suggest that the problem lies in the misunderstanding of what constitutes exercise for the bone tissue.

We hypothesize that bone in a state of equilibrium must be a unique function of a daily remodeling stimulus rate which is itself a function of the load history. Thus, if one suddenly increases (decreases) his/her level of physical activity, the daily rate of applied stimulus is increased (decreased), and bone will establish a new equilibrium density.

We further hypothesize that bone density is precisely modulated to provide the bone tissue with a constant level of stimulation. Since body weight, height, daily activity level, and exercise all contribute to the loading history, the daily remodeling stimulus becomes a

fundamental variable for bone density normalization.

Progress—We have selected accumulated daily cellular microdamage as an appealing first choice for the remodeling stimulus. It forms a convenient method for condensing a complex load history into the weighted summation of two essential parameters.

Equations for damage accumulation were developed for differential bone volumes to obtain density ratios as a function of the change in local remodeling stimulus. Integration of these relationships over the entire bone volume resulted in equations which yield a bone density scale factor as a function of an external load scale factor. A set of activity levels for the calcaneus was constructed which encompassed near immobilization to vigorous athletic activity.

Preliminary Results—Expected bone densities for each activity level were calculated and compared to the literature with excellent results. These results have immediate clinical relevance which we are addressing. Stated briefly, high cyclic loads are the most effective means of increasing bone density. Jogging, which does not develop high loads, is not very effective in terms of the time spent exercising. For example, we predict that jogging 4 miles per day will increase calcaneal density by only 5 percent. Since ground-reaction loads attenuate vertically, the benefit to the axial skeleton and upper limbs will be even less.

Future Plans—We are currently combining the results of this work with earlier work done by our group. Our intention will be to demonstrate the equivalence of fatigue damage accumulation and a more fundamental energy term expressed as an effective stress.

Prediction of Cancellous Bone Apparent Density and Orientation

Dennis Carter, Ph.D., and David Fyhrie, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Normal activities cause cyclical loadings which may lead to application of a physiologically normal average stress state for all regions of cancellous bone. Since the observations of Wolff and von Meyer, it has been generally accepted that the trabecular orientation and apparent density of cancellous bone are functions of this average stress. However, the exact relationship between stress and bone remodeling is not known.

The ability to predict the response of cancellous bone to applied stress is critical to the evaluation of new prosthesis designs. If the bone response to implantation of a new prosthesis could be accurately predicted, expensive experiments could be avoided. The reliability of joint prostheses would be greatly improved and the time required for design and testing of new design concepts dramatically reduced.

While the exact relationships between applied stress and cancellous bone morphology

are not known, two hypotheses have been put forward:

1. The direction of the bone trabeculae is parallel to the predicted principal stress directions; and

2. The apparent density (bone mass per unit volume) is related to the relative sizes of the principal stresses, as a function of the von Mises stress. These hypotheses have been tested. The first has been strongly supported, but the second has been shown to only be true under certain restrictions.

To unify the two hypotheses and remove the restrictions on the second hypothesis, we assume that cancellous bone is an anisotropic material and hypothesize that it has two goals; first, to maximize its structural integrity, and second, to minimize the amount of bone tissue. The attempt to meet these conflicting goals simultaneously leads to a unifying optimization principle governing the remodeling of cancel-

lous bone. This new theory predicts both trabecular orientation and density.

Progress—To determine the best orientation for the bone trabeculae and the minimum bone apparent-density needed to carry the stresses, we use a single optimization principle. Stated generally, the principle assumes that there is a relationship among stress, bone apparent density, and orientation of the anisotropy of the bone, and that this relationship measures how well the bone meets the conflicting goals of the bone growth hypothesis. Using special forms of that relationship, we have shown that the optimal orientation for the bone is with the trabeculae (anisotropy) aligned with the principal stress directions—just as is observed in living bone.

We have also determined a relationship between bone density and stress, making it possible to predict bone density from stress analyses. It seemed that the relationship between stress, apparent density, and bone orientation governing the remodeling of cancellous bone might be the amount of energy stored in the bone tissue

due to its deformation under load. Using this stored energy approach, the function governing bone optimality is the strain energy density (SED) of bone tissue in the cancellous bone. Using the SED to determine the apparent density of the bone, we derive the relationship that bone apparent density is proportional to the square root of SED where the SED is evaluated for a reference density.

Preliminary Results—The SED in the bone can be found using finite element analysis. We have conducted a three-dimensional finite element analysis of the femoral head and neck and have predicted the cancellous bone apparent density in the femoral head. The resulting predicted density patterns are similar to those found in real femoral heads. This is the first time that cancellous bone's apparent density has been predicted in three dimensions. Therefore, this new theory is seen as a promising step towards the ability to predict accurately the changes in cancellous bone following implantation of a joint prosthesis.

Development of a Musculoskeletal Model of the Human Lower Extremity

Felix Zajac, Ph.D.; Melissa Hoy, Ph.D.; Michael Gordon, M.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Computer simulation studies of the human neuromusculoskeletal system are needed to understand the function of different muscles during movement. Thus, a musculoskeletal model of the human lower limb must be developed to study intermuscular coordination of even such apparently simple movements as standing and walking.

In addition to their use in studying muscle coordination as it occurs in able-bodied persons, musculoskeletal models can also be used to determine how to compensate for lost muscle function in disabled persons. For example, they can help determine which muscles should be stimulated and what activation pattern should be used to achieve standing and walking. This will aid in the design of functional electrical

stimulation (FES) systems for persons with paralyzed lower limbs.

Progress—We have developed a musculoskeletal model of the human lower limb to study muscle function in the sagittal plane. With our model, we have completely specified the muscle parameters and musculoskeletal geometry for 24 muscles acting at the hip, knee, and ankle joints.

We have found that the range of joint angles over which a muscle generates torque is unique. By characterizing the torque-producing capability of each muscle, our model provides a basis for understanding intermuscular coordination in both able-bodied persons and in disabled persons using FES.

Future Plans—In the future, we plan to expand the model to study muscle function in the frontal and transverse planes. Because the muscle parameters are scalars and the musculoskeletal geometry is already specified in three

dimensions, only the joint models need to be modified.

Also, the metatarsophalangeal joint will be incorporated in the model to aid in the study of intermuscular coordination during propulsion.

A Musculotendon Actuator Model for Use in Computer Studies of Neural Control and Biomechanics of Movement

Felix Zajac, Ph.D., and William Levine, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Computer models of the neuromusculoskeletal system require a model of each muscle and tendon (musculotendon actuator) under study. Models of musculotendon actuators, when imbedded into musculoskeletal computer models, will have usefulness in studies of neural control, muscular coordination, energetics, and biomechanics of movement.

Because hardly any of the significant musculotendon variables can be measured in humans during movement, musculotendon actuator models are virtually the only means by which to gain knowledge of *in vivo* musculotendon action. A large number of muscle models have been proposed. They can be classified into subcellular models and mechanical (input-output level) models. The subcellular models are primarily used to study molecular and biochemical events and are too computationally complex for our study of coordination. The mechanical models could be used in our study, even though specifying model parameters for each muscle would be a major problem, but most of them fail to take into account the effects of tendon, which is an important part of the musculoskeletal system.

Our goal is to construct a new, computationally efficient model of muscle mechanics that takes tendon explicitly into account and that can be scaled by a small number of parameters to represent a wide class of specific musculotendon actuators.

Our approach to modeling muscle and tendon is to base the model on musculotendon architecture and fundamental mechanical properties of muscle fibers and tendon. The basis of

this formulation is the arrangement of muscle fibers with respect to tendon (pinnation angle), the arrangement of sarcomeres within a muscle fiber and of fibers within a muscle, the mechanics of sarcomeres when passive and activated, the dynamics associated with excitation-contraction coupling, and the constitutive (stress-strain) properties of tendon. The model is to be structured so that its dynamics are low-order and dimensionless and so that it can also be scaled to emulate the force-length, force-velocity, elastic, and activation properties of muscle and tendon.

Progress—A dimensionless, first-order model of musculotendon contraction dynamics has been developed. Only three actuator-specific parameters (muscle strength, optimal muscle fiber length, and tendon slack length) are needed to scale the generic representation to a specific actuator. The musculotendon actuator model has been simulated on a computer, and investigations are ongoing.

Preliminary Results—We have shown that tendon can be a dominant factor in musculotendon mechanics and that the degree to which musculotendon properties are affected is muscle-specific, at least for human lower-limb muscles.

When muscle fiber orientation is considered, the model changes only in algebraic complexity, though another actuator-specific parameter is required.

We are developing a first-order model for the dynamics associated with muscle activation.

Thus, the complete dynamics used to describe musculotendon mechanics will be second-order.

Finally, the current model can be amended

for use in studies of functional neuromuscular stimulation.

Neuromuscular Control and Biomechanics of Pedaling and Jumping

Felix Zajac, Ph.D., and William Levine, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Some motor tasks that pose challenging intra- and interlimb coordination problems can be studied relatively simply by using computer modeling techniques in addition to traditional experimental techniques. Presumably, these techniques when taken together will shed light on the energetics of the task (i.e., how the energy produced by the muscles is stored in their musculotendon actuators and transferred from one actuator to another and to the mass segments of the body).

If we can show that computer modeling and experimental techniques together lead to a better understanding of coordination than either technique by itself, we will thereby demonstrate the utility of computer models in studies of movement. The modeling approach could then be applied to more complex movements, including those of disabled persons. It may be possible some day to base rehabilitation strategies in part on computer-aided design methods.

Our approach in this research is to study the coordination and energetics of jumping and pedaling, using computer simulations and experiments.

Progress—Our first simulations employed a simple two-segment jumping model to investigate the rudiments of jumping dynamics and energetics and to evaluate various models of the musculotendon actuator.

We are currently developing a more sophis-

ticated neuromuscular-control jumping model that includes 24 human lower limb muscles acting on four articulated body segments. The model allows muscle activation (coordination) patterns to be specified automatically (so as to satisfy an optimality criterion) or manually. We are also working on a version of this model for pedaling.

We are also developing a movement-monitoring system for use in experiments on human jumping, posture, and gait, and we are building a pedaling apparatus to study the neuromuscular control and biomechanics of interlimb coordination during common and novel pedaling tasks.

Preliminary Results—As a result of studying a one-muscle, one-degree-of-freedom computer jumping model, we have been able to define the essential features for modeling the musculotendon actuator. We found that the musculotendon actuator can operate in different ways. For example, in jumping from a squat, the quadriceps generates the work output needed to propel the body, whereas in jumping subsequent to a fall, the quadriceps acts like a spring, storing energy during the fall and then releasing it to the body during propulsion.

We are currently integrating all our models into a complex neuromuscular control model and investigating algorithms to compute optimal coordinated activation patterns.

Intermuscular Coordination of Mammalian Movement

Felix Zajac, Ph.D., and William Levine, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor—VA Rehabilitation Research and Development Service

Purpose—Rehabilitation of persons with severe motor disorders demands an understanding of the neuromusculoskeletal control mechanisms involved in movement. However, from a neuromuscular point of view, even the simplest movements are very complex, and multijointed movements involving the coordinated action of more than one muscle are, at present, only poorly understood. The goal of this project is to develop techniques for quantitatively analyzing intra- and inter-limb coordination.

The computational and experimental techniques developed in this project should be useful in studying lower extremity motor tasks such as maintaining proper posture, walking, and pedaling in the able-bodied and the disabled. Furthermore, they should shed light on optimal strategies for motor rehabilitation, reconstructive orthopaedic surgery, functional neuromuscular control of paralyzed muscles,

and orthotic and prosthetic design.

Progress—We are currently developing a musculoskeletal model of the human lower limb with three parts: a muscle model, a musculoskeletal geometrical model, and a multi-segmental dynamic body model. Each part is generic, and it will be possible to scale the model to match a particular person's anatomy and physiology. We are also modeling the interaction between the body and its environment for the specific tasks of jumping and pedaling, and we are integrating all the models to allow detailed simulation of intra- and interlimb coordination of human lower extremity muscles.

In parallel, we are developing experimental techniques for monitoring body motion, body kinetics, and muscle activity during jumping, standing, and walking.

The "White Knuckle" Technique for Studying Skin Behavior Under Load

Alvin H. Sacks, Ph.D., and Inder Perakash, M.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The problem of studying skin blood flow response to external loading, which is believed to relate to pressure sores, usually involves rather sophisticated instrumentation. In the work reported here, a much simpler technique is explored; it involves the whitening of a knuckle in the bent finger.

A simpler technique for studying skin blood flow response to loading, especially one involving simple finger-bending and length measurements, would offer the possibility of a clinically feasible screening test for identifying those patients who are more prone to pressure sores. This could be important in redistribution of nursing care to minimize the occurrence of pressure sores in VA hospitals.

When a human finger is bent at the knuck-

le, there is a whitening of the skin caused by stretching of the skin over the knuckle. This whitening seems to occur at a specific angle of bend for a given subject. The phenomenon is related to the classical engineering problem of the tension in a pulley cable, in which the tension is balanced by a corresponding outward pressure provided by the pulley. In the case of the finger, the tension in the skin produces a corresponding pressure on the knuckle which causes the blanching of the skin. It therefore offers a potential alternate method of applying known pressure loads to the skin in order to study elastic behavior and blood flow response—without measuring the flow itself.

Before embarking on any such set of experiments involving physical variables, it is

prudent to first carry out a dimensional analysis in order to be sure that we measure all of the important parameters and that we treat them properly in analyzing the data.

Progress—We have made preliminary measurements of knuckle angle and skin elongation on four able-bodied and four paraplegic male subjects and find that they all have essentially the same characteristic curve of elongation vs. angle, in the form of two nearly straight-line segments. In all cases, the slope changes rather abruptly at the angle at which the knuckle 'wrinkles' disappear, since this point represents the initiation of pure skin stretching.

Preliminary Results—Once the skin begins

pure stretching, the slopes of the curves seem to be relatively consistent and are apparently about 20 percent (mean value) lower for the subjects with paraplegia, indicating that the skin has lost some of its elastic strength and therefore stretches more easily in the paraplegic subjects. It was also noted that knuckle whitening seems to appear consistently for the able-bodied subjects at an angle of about 90-to-100 degrees. The paraplegics, on the other hand, seem to show a later and less definite whitening.

The number of subjects tested so far is clearly too small to permit any valid conclusions, and systematic measurements of skin thickness and radius of curvature remain to be done.

Bone *In Vivo* and *In Vitro* Stress and Strain Patterns: Influence of Age and Activity_____

Dan M. Spengler, M.D., and Tony S. Keller, M.S.E.

Department of Orthopaedics and Rehabilitation, Vanderbilt University, Nashville, TN 37232; Orthopaedic Biomechanics Laboratory, Veterans Administration Medical Center, Nashville, TN 37203

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of this study is to examine the effects of aging and activity on the bioelectric and biomechanical response of cortical bone from a wide range of animals.

Progress—Growing and adult rats were subjected to various activity regimens, including cage, hypoactivity, and hyperactivity. *In vivo* and *in vitro* biomechanical (bending and torsion tests) and bioelectrical changes associated with aging and activity level were assessed from measurements of bone strain and current. The former were determined from miniature strain gauges bonded to the bone surface, whereas the latter were measured using a noncontacting electromagnetic device developed in our laboratory. Histomorphometry of tetracycline-labeled cross-sections was performed in order to determine bone geometric properties and growth rates. Similar biomechanical and histomorphometric examination of long bones from normal growing primates (baboons) was performed in order to provide quantitative information on this larger animal group.

Preliminary Results—In normal growing animals, both geometric and material properties are regulated in order to maintain an optimal bone strength. In rapidly growing animals such as the rat, material changes dominate, whereas in slowly growing animals geometric changes dominate. Analysis of the fracture strength due to torsional loading of immature rat and monkey femora indicated that the torsional strength scales across a broad range of animal sizes in spite of differences in geometric and material scaling strategies. A fracture strength index $S_b = T/L$ was formulated, where T = bone strength and L = bone length. S_b was found to increase allometrically ($Y = ax^b$) with animal mass, and an exponent $b = 0.93$ was obtained, indicating that bone strength relative to body mass may decrease slightly during maturation for these animal groups. S_b therefore may be a common scaling factor by which growing animals modulate bone strength.

Both intensive exercise (> 0.5 km/day) and hypoactivity (simulated weightlessness) in the rat were found to induce bone hypotrophy

(length and girth) and resulted in significant decreases in structural and material properties during maturation. Moderate exercise (< 0.5 km/day) appears to have no effect on these properties when compared to caged controls. Both exercise and hypoactivity may alter the compressive forces on long bone epiphyses, the latter of which may have an optimal stress range for normal function. Stress-induced changes in bone piezoelectric properties may also play an important role.

Future Plans—Recently, we have developed a split-core, noncontacting electromagnetic toroid

with which the magnetic field, created by stress-induced current flow (streaming potentials), can be measured in wet, intact long bones. Preliminary *in vitro* results indicate that a current potential of approximately 1.0 microampere is obtained during application of bending moments equivalent to the body weight times bone length of the animal. Examination of the effects of loading frequency, aging, and activity on both *in vitro* and *in vivo* current potentials and corresponding strain levels in future experiments may provide considerable insight into the process of bone adaptation.

A Model for Postural Sway

Serge H. Roy, M.S.P.T., and Carlo J. De Luca, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: Liberty Mutual Insurance Company

Purpose—When an individual stands erect, the body makes minor movements over the location of the feet. The human body is incapable of remaining perfectly still. Furthermore, the task of standing erect is in itself a considerably complicated task, which individuals accomplish with various degrees of ease. We are interested in understanding the mechanisms that control posture for the purpose of measuring and quantifying the amount of dysfunction in individuals with movement disorders.

Progress—Toward this goal, we have begun to measure and analyze the stabilograms of individuals. Stabilograms are the plots that describe the continual displacement of the center of pressure (sway) in the horizontal plane of the feet as an individual stands still. Stabilographic

measures have been used for many years, but their usefulness has not lived up to expectations, mainly because the tracings thus obtained do not have a well-defined parametric behavior.

Our approach to modeling the behavior of the stabilogram is to consider the sway as a random variable that may be described by Brownian motion.

When the stabilogram is plotted as a variable of the diffusion equation that describes Brownian motion, the resulting curve suggests that the modeling approach is correct. We plan to continue studying the applicability of the model with the intention of extracting information concerning the control properties that govern postural sway.

Measurements of Postural Sway

Rami Bushnaq, B.S., and Serge H. Roy, M.S.P.T.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: Liberty Mutual Insurance Company

Progress—During the past 4 years, the NeuroMuscular Research Center has accumulated a large inventory of data describing postural

equilibrium in healthy individuals and in patients with neurological disorders. The tests were conducted in our Motion Analysis Labora-

tory using a force platform to measure postural sway and to display the results in the form of a stabilogram.

We are currently reevaluating these data to test a new mathematical model for postural sway. Unlike standard methods of interpreting stabilograms, the results based on our model clearly emphasize differences in postural sway and provide a means of understanding the motor-control scheme that directs the movement. To further understand the model as a control process, we have also begun to apply

mathematically generated "sway paths" to the model. The behavior of the model in response to different stochastic and nonstochastic processes, with and without boundary conditions, is being studied.

Additional tests have also been performed to study the intrasubject and intersubject variability of stabilogram data when fitted to the model. Preliminary results are favorable to developing this method into a clinically useful tool.

Visuomotor Effects on Postural Sway

Diana Shulmann, M.S.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—Vision aids us in maintaining our upright balance or posture. It has other functions, however, that may be incompatible with postural control. By employing different eye movements, we know that our perception of visual field motion changes. This study sought to determine the influence that eye movement has on postural control. We predicted that only those movements that yield a stable optical array would improve postural stability. Quick, jerky eye movements called saccades satisfy this condition, whereas smooth-pursuit eye movements do not.

Progress—Subjects stood on a strain gauge force plate and moved their eyes at various frequencies of saccade and smooth-pursuit. Results of the study showed that saccadic eye move-

ments yielded less sway than smooth-pursuit eye movements. This effect was independent of frequency and length of fixation time. Practically speaking, these results show that a person is more stable when his or her eyes are scanning the environment (saccading) as compared to following (tracking, pursuing) a moving object.

These results have important therapeutic implications. Many patients with neurological deficits and/or visuomotor palsies of vestibular dysfunction have balance disturbances. These patients require therapy to regain control over posture. This work gives us some meaningful insight into the methods by which visual intervention can become a worthwhile modality for such persons.

Gross Motor Behavior in Late Childhood and Early Adolescent Children with Down's Syndrome

Alice Shea, P.T. M.S.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Boston University*

Progress—Data collection for this study of motor behavior in children with Down's syndrome was completed in fall 1985. A total of 62 children with Down's syndrome and 20 of their

normal siblings were seen. Thirteen other children with Down's syndrome were seen at their homes. These children were part of an original group of 89 children with Down's syndrome

who were followed for their first 3 years at the Children's Hospital Developmental Evaluation Clinic in Boston.

Data analysis is currently under way. The data set includes measures of motor skills, postural sway, and joint range of motion. Height, weight, pubertal stages, and indicators of obesity, as well as severity of congenital heart disease, will also be included in the analysis. This will allow us to examine the interrelationships of these variables using multiple regression. We will also look for relationships between early motor attainments, for which we have a broad database, and later will monitor performance.

Overall, the study should lead to a better understanding of later childhood motor performance in children with Down's syndrome, an area in which little information is available. The information should be useful to educators, therapists, and physicians. The results of the postural sway analysis will be particularly useful in documenting the clinical observations of balance problems in these children. The information about possible antecedents of present motor abilities will be of value to both parents and professionals who are involved in early treatment of children with Down's syndrome.

Visual Control of Step Length During Running

William Warren, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company and Brown University*

Purpose—If they are to be adaptive, movements produced by the motor system must be coordinated with features of the local environment. This is where visual perception has a role to play in the control and coordination of movement. Our research on this problem seeks to identify optical variables that are utilized to regulate specific motor parameters during the performance of coordinated action. For example, we have been studying the way in which step length during running is visually adjusted to ground-surface irregularities, such as oddly spaced patches of bare ground. By using the

force platform in the NeuroMuscular Research Center's instrumented walkway, we were able to confirm earlier results indicating that runners alter step length by modulating a single gait parameter, the vertical impulse that they apply to the ground during stance. A simple model suggests that vertical impulse can be directly modulated by the visually perceived time before contact with upcoming targets. Rehabilitation programs might apply such research not only to retrain specific movement patterns but also to retrain the ability to use visual information to regulate specific parameters of action.

Modulation of Tonic and Phasic Reflexes with the Skin

M. Sabbahi; C. Mason; E. Lou

Motor Control Laboratory, School of Physical Therapy, Texas Woman's University, Houston, TX 77030

Sponsor: *None Listed*

Purpose—The interplay of the basic and tonic components of the stretch reflex is essential for smooth and more controlled movement performance. The effect of cutaneous feedback information on this phasic-tonic interplay is not very well understood. This information is crucial for developing rehabilitation methodologies for patients with neurological disorders. It is

also helpful in understanding movement performance in legally blind subjects who depend on afferent feedback (including cutaneous feedback) in their movement.

This report discusses the modulation of tonic vibration (tonic) and H-reflexes (phasic) of the upper limb muscles after desensitization of the skin.

Progress—Flexor carpi radialis (FCR) H-reflex and biceps brachii (BB) tonic vibration reflex (TVR) were recorded as indices of the excitability of phasic and tonic MNP, respectively. H-reflex was elicited by 1 ms, 0.2-pps pulses for the median nerve at the elbow, and TVR was elicited by applying an air-driven vibrator on the biceps tendon at 80 pps for a period of 60 seconds. FCR and BB EMG and elbow flexion torque were recorded before and after desensitization of the anterior forearm (AF) or posterior forearm (PF) skin areas using topical anesthesia (10 percent xylocaine) or a placebo.

Preliminary Results—Desensitization of AF skin area resulted in significant ($p < 0.05$) facilitation of the FCR H-reflex and significant

inhibition of the BB TVR and decreased flexion torque. This effect lasted for 30 minutes postanesthesia. No measurable changes were recorded in either reflexes or the torque after desensitization of PF skin areas or after the placebo.

These results indicate that cutaneous receptor afferent discharges of flexor skin area simultaneously inhibit phasic reflexes/motoneurons and excite tonic reflexes/motoneurons of flexor MNP. These results also suggest that there is a spontaneous ongoing activity from cutaneous receptors modulating these reflexes simultaneously. It appears that cutaneous receptor afferents play a major role in increasing muscle stiffness and damping responses to external perturbation, resulting in a more smooth movement performance.

Electromagnetic Modulation of Cellular Interaction in Natural and Foreign Environments in Bone

Dr. A. K. Rakshit

Hospital of St. John and St. Elizabeth, 60 Grove End Rd., London NW8, United Kingdom

Sponsor: *None Listed*

Purpose—The biology and function of the skeletal system including joint structures are singularly important. The repair processes of the articular cartilage are being intensively studied both in disease and in trauma in the attempt to prevent degenerative and rheumatic diseases and to rehabilitate various forms of disabilities. The objective of this study was to highlight the importance of research on pulsating extremely low frequency fields on osteoarthrology.

Cellular interaction in the osseous tissue involves at least two distinct mechanisms. In microhistological studies, osteoclasts responsible for bone absorption are seen directly in the vicinity of the absorption area. Osteoblasts in the active form are further away from where the bone is being actually laid down (until osteoblasts become osteocytes and cease production of osseous tissue).

The cellular interaction depends on the form of stimuli of:

a) Biochemical (antibiotic) cytotoxic drugs. The chemical structure of the biomolecules (e.g., fibrous and globular proteins) is function-

related, and their diversified functions depend on the extensive range of structural conformations and flexibility prevalent in biological interactions. A relatively small drug molecule combines with functional groups (called receptors) of a macromolecule. The small drug molecule induces a change in the electrical charge distribution of the whole macromolecule, which leads to a change in the conformation, orientation, and function of the large biomolecule present either on the cell membrane or inside and outside of the cell. A platelet-derived growth factor (PDGF), structurally a protein, is also responsible for cellular growth at the tissue level on site, but its contribution is not quite certain.

b) Endocrinal/hormonal stimuli (e.g., parathyroid hormone, pituitary growth hormone).

c) Electromagnetic or bioelectrical signals (e.g., direct or induced).

d) Mechanical, traction, manipulation, or other movement, or lack of movement (i.e., rest and immobilization).

Here, we deal only with electromagnetic or

bioelectrical signals. The different areas of the electromagnetic spectrum have different biological interaction. The biocoupling of low-intensity, extremely low frequency (ELF), nonionizing, isothermal radiation has either a stimulating or inhibitory effect on cell metabolism.

Osteoarthritic people suffer from common ailments, moderate to severe pain, stiffness of various joints, lack of mobility or severe restriction of movements, and poor biological function as a male/female partner. The treatment with ELF and low-intensity electromagnetic irradiation of affected joints or parts of the body improves not only the symptomatology but also the quality of life. Apart from the subjective improvements, significant changes are noticed in the radiological appearances of the joints. This may mean that not just the arrest of an otherwise progressive disease but its reversal—at least in some cases—can be indisputably established from a series of radiographs.

Therapeutic applications include patients who are waiting for prosthetic operations. The curative role of pulsating electromagnetic radiation of low frequency and low intensity has been established. In the early cases of degenerative arthritis, patients were suffering from arthritis for the past 10 to 15 years and were not responding adequately to analgesics, anti-inflammatory, and nonsteroidal drug therapy. Unfortunately, conventional physiotherapy, including ultrasound/shortwave therapy, is not much help in most cases. The subjects are either on the waiting list or are prospective candidates for future replacement surgery.

Another therapeutic application is treatment ancillary to replacement surgery in advanced or late osteoarthritis of 15 to 30 years' duration: a) preoperative treatment before prosthetic replacement of the diseased synovial joint for histological studies on replaced joints that have been irradiated by electromagnetic radiation before the replacement operation, the preparation for a better foundation for prosthesis to be embedded in the bones in case of widespread osteoporosis, and the improvement of revision rates and failure rates of the prosthetic operation in the treated joints; b) postoperative treatment to prevent early infection and move-

ment of prosthesis as a prophylactic measure; or c) late or delayed treatment after hip replacement operation (e.g., in the same hip for osteoporosis or fracture complications, or in the contralateral hip for progressive osteoarthritis).

Still another therapeutic application is to prevent arthritic changes from developing in the adjoining synovial joints leading to replacement surgery at a later date, such as delayed or nonunion fracture cases involving joints with developing osteoarthritis and osteoarthritis as associated with grossly disabling soft tissue injury in ankle or knee or contracture of hand.

A final therapeutic consideration is for the palliative treatment for excruciating pain and progressive stiffness in already deformed, longstanding arthritic elderly subjects, (e.g., osteoarthritis in wrists where prosthetic operation has been ruled out). The objective is to improve the quality of life.

Preliminary Results—The mode of action is one of the intriguing subjects in modern bioelectrochemistry. Vital processes in the cells are associated with bioelectrical potential differences. The biopotentials are, in turn, dependent on the ion concentrations of the internal and external environments of the cells. The ion concentration varies as the rate of dissociation and recombination of ion pairs in solution. The intensity of the transport process of the cell membrane as well as the intensity of the metabolic processes inside the cells depend on the ion concentration.

More attention should be paid to the electrical characteristics (e.g., biopotential sensitivity leading to changes in the transport and metabolic processes in cells). In arthritis, evidence is accumulating of the altered metabolic activity of the cell resulting in changes in the biopotential differences, or vice versa. Thus, the measurement of biopotential differences can undoubtedly serve in estimating the intensity and nature of the metabolic processes in the cells.

This conclusion results from the parallel isotopic study, the electron-microscopic investigations, and the explanation of the electrical parameters of similar structures. For example,

fracture studies show that the fracture site is persistently and consistently electronegative in relation to the undisturbed distal end of the same bone. This electronegativity of the interrupted bony tissue is reversed depending on the intensity of the healing processes; that is, the intensity of the metabolic activity of the different types of bone cells as demineralization or mineralization are taking place. In case of cartilaginous tissue affected by arthrosis, metabolic processes typical of cartilaginous tissue take

place in early cases when treated, whereas more sclerosis is seen in late cases as evidenced in X-rays of the relevant joint surfaces and surrounding areas. It may mean for the future that it is possible to reverse the pathological processes in osteoarthritis cases and to control the aging process. The future thus holds promise for sufferers of degenerative or rheumatoid arthritis through the efforts of medicine, surgery, physiotherapy, and electrobiology.

Enhancement of Union of Segmental Defect Fractures

Kenneth D. Johnson, M.D.

University of Texas Health Science Center at Dallas, Dallas, TX 75235

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Large diaphyseal defects in long bones continue to challenge surgeons who deal with trauma, tumor resection, infection, and leg-lengthening procedures. Autogenous bone grafts require major surgical procedures with significant associated morbidity with only a finite amount of material available. New alternatives such as allografts, bone derivatives, and synthetic materials appear on the horizon. These alternatives hold promise but need further evaluation to compare their efficacy with currently available techniques of bone grafting. Because of variations between individual animals, the need exists for control of bone graft studies within the individual animal rather than comparison of results from animal to animal. This study was performed to define a bilateral diaphyseal defect model in a weight-bearing bone of the dog as well as to study the efficacy of morselized cortical bone as a bone graft material.

Progress—Sixteen adult true-bred foxhounds, weighing between 25 and 35 kilograms, were subjected to bilateral surgical procedures that created a 2 cm defect in the distal half of each radius. Periosteum was carefully excised and removed with each cortical segment. All defects created were stabilized with a single-bar tubular external fixator placed on the anteromedial surface of the foreleg. Eight control dogs had

one side grafted with morselized autogenous cancellous bone obtained by curettement from the contralateral humeral head. The opposite side received no graft material. Eight study dogs were treated with morselized cancellous bone on one side and morselized cortical bone on the other side. Morselized cortical bone of a particle size from 250 microns to 2 mm was created by grinding the removed segments of cortical bone from both defects in a sterile grinder for 3.5 minutes. Prior to grinding the cortical bone, all soft tissue (periosteum and marrow) were meticulously removed. The dry weight of cortical bone used in each defect averaged 1.8 ± 0.2 grams for cortical bone and 0.8 ± 0.2 grams for cancellous bone. All dogs were allowed full weightbearing activity postoperatively. Serial radiographs were obtained to assess graft incorporation. Dogs were sacrificed at 12 and 24 weeks in both the control group and the study group. All radii were explanted and tested to failure on a Burstein-Frankel torsional testing apparatus. Histology was performed using a microscope. Nine normal radii from the same size and breed of dog were also explanted and tested to failure in torsion to give comparative data. Pin tract infections with the external fixator were a minor problem and required some adjustment in the technique and position of pin placement. These infections did not involve the bone graft site and were controlled by

local wound care.

Preliminary Results—Two dogs were lost because of early, overwhelming infection and were replaced with fresh animals. At both 12 and 24 weeks, the control group of resected, but not grafted, defects showed a 100 percent rate of nonunion radiographically. Morselized cortical bone graft also showed a 100 percent nonunion rate with no major difference in bone volume or histology when compared to the non-grafted defects. All cancellous bone grafts united rapidly and then consolidated. Results of torsion testing are reported in values of maximum torque to failure in the 12- and 24-week specimen. Cancellous grafts showed 30 to 50 percent of the strength of a normal dog radius. Morselized cortical graft and no bone graft demonstrated 0 to 10 percent of normal dog radii, whereas morselized cortical bone and no graft continued to show 0 to 10 percent of the normal dog radius, indicating a nonunion. The cancellous grafts had recanalized completely at 24 weeks and appeared as normal bone histologically. Radiologic evaluation demonstrated almost complete resorption of morselized corti-

cal bone, which was confirmed by histology. Histology revealed the presence of a fibrous nonunion with an occasional pseudarthrosis in the defect and morselized cortical bone specimen.

This bilateral dog radius model provides a weightbearing bone in which a consistent nonunion can be created. At the same time, the stability of the bone can be controlled, allowing the animal normal activity. This model should be useful for the comparison of various new bone-graft materials and substitutes using the individual animal as a control. Cortical bone, alone, which is morselized by means of power grinding, has little or no osteoinductive of its own and should not be used as a bone graft material without the addition of some other osteoinductive material (bone marrow elements). Autogenous cancellous bone graft is an ideal bone graft material for diaphyseal defects even in the absence of periosteum. It has excellent osteoinductive capacity, is rapidly vascularized and incorporated, eventually consolidates, and then recanalizes to an appropriate strength level.

VII. Wound and Fracture Healing

Electrical Stimulation for Augmentation of Wound Healing

Scott R. Crowgey, M.D., and Steven M. Sharpe

Veterans Administration Research and Development, Decatur, GA 30033

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—This project will attempt to identify aspects of the wound healing process that may be augmented by the exogenous influence of electromagnetic fields. A theoretical analysis of the possible effects of electromagnetic fields on wound healing will include analyses of the interaction of electromagnetic fields with cellular structures and of the deposition of heat in damaged tissue via exogenously applied energy fields. This analysis will then be used as a basis for developing a plan for future investigations into the potential application of electrical stimulation for the augmentation of wound healing.

The initial research will involve a review of the literature to identify aspects of wound heal-

ing that could be influenced by electrical stimulation. Efforts will then be directed toward developing mathematical models of the possible electrical interaction of electromagnetic fields with cells and cell structures to determine how these interactions could be optimized to improve wound healing. It is anticipated that the literature will not contain all the information necessary to develop these models. Any gaps in necessary information and data will be filled, if practical, using tissue phantom modeling materials, blood, and possibly even primitive tissue culture exposed to a variety of known electromagnetic environments, using easily constructed exposure chambers.

Development of a Mathematical Model of Fracture Healing in Long Bones

Gary Beaupre, Ph.D., and Dennis Carter, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—When a long bone is fractured, its mechanical properties change significantly as the bone heals. However there is very little quantitative information on how mechanical stresses influence the healing process and on how the mechanical properties of the fracture site change as the bone regenerates back to its original shape and structure.

Much attention has been given to the development of fixation devices for fractured long bones, and many different mathematical models have been used to evaluate the stress states and deformations caused by the application of these devices. The mechanical properties assumed at the fracture site influence the results of these analyses. The development of a mathematical model to quantify how a bone

heals in the presence of different stress states and how the mechanical properties change accordingly will offer insights into the fracture healing process for both normal and pathological healing situations. A better understanding of fracture biomechanics will provide guidelines in the design of treatment modalities for fractures and fracture nonunions.

To date, there have been numerous histological and morphological studies on the healing process of fractured bones. The healing process has been categorized into four basic phases: 1) initial reformation of the vascular system with formation of soft callus tissue; 2) formation of cartilaginous callus; 3) formation of bone tissue; and 4) remodeling of bone tissue. These sequential phases stabilize and progres-

sively stiffen and strengthen the healing bone.

Some data are available on the mechanical properties of the tissues involved, but no models exist that can describe or predict this healing process. Our hypothesis is that the transition from the initial phases of fractured bone to its original structure, in particular from the cartilaginous stage to the formation of bone tissue, is influenced by the local state of stress and strain within the tissues participating in the healing process. As healing proceeds, the material and structural properties of the fracture are changed, resulting in a progressive increase in the structural integrity of the bone.

Progress—The finite element method is being used to create a mathematical model of a fractured long bone. The idealized bone is based upon the midshaft geometry of the human

femur. The appropriate loading and boundary conditions are obtained from previous studies using: 1) load-sensing implants and prostheses; 2) *in vitro* experiments; and 3) static and dynamic mathematical models of lower limb forces. An iterative mathematical procedure that triggers the transformation of cartilage into bone will be used. This procedure will permit the temporal and geometric pattern of healing to be both predicted and followed.

In this study two- and three-dimensional nonlinear finite element models of an idealized fractured bone are being developed. Initial fracture callus geometry was determined from previous studies. Preliminary studies suggest that the local strain energy density is a likely candidate for the controlling mechanism that triggers the transformation from cartilage into bone.

Bioelectricity in Fracture Healing

John F. Connolly, M.D.; Dennis A. Chakkalakal, Ph.D.; Louis Lippiello, Ph.D.

Veterans Administration Medical Center, Omaha, NE 68105, and the University of Nebraska Medical Center, Omaha 68131

Sponsor: VA Rehabilitation Research and Development Service

Purpose—To investigate the role of bioelectricity in fracture healing, two research projects are under way: "Electrical Osteogenesis: Mechanisms and Causes of Failure," and "Scientific Basis for a New Protocol in External Fixation of Fractures." The basic knowledge of bioelectricity's role derived from these studies will be used to identify electrical signals that will be most effective in promoting healing in fractures that are difficult to heal. In patients with an osteoporotic condition, external fixation is preferred over internal fixation. However, external fixation has a tendency to delay fracture healing. Therefore, we are attempting to identify electrical signals that may be applied to prevent such a delay.

Progress—We are developing objective methods for measuring the rate of return of mechanical rigidity, bone blood flow, and skin-surface electrical activity toward normal in fracture healing in dogs so that these can eventually be used

in humans for diagnosis of problem fractures, for choice of the optimum method of treatment, and for prognosis of all fractures.

We used both internally fixed and externally fixed long-bone fracture models (radius and tibia) in dogs that heal normally and those that are delayed to carry out our studies according to the following two themes:

A) Characterize these long-bone fracture models through biomechanical, physico-chemical, vascular, histomorphometric, and biochemical measurements so that we can understand details of the differences between a normally healing fracture and a delayed-healing one.

B) Investigate roles of electrical activity that occur in living systems naturally following injury and of externally applied electricity in altering the various features of these fractures revealed from the above study.

Preliminary Results—From the studies under theme A, we obtained the following results: 1) a

method for determining an index of rigidity of the fractured bone; 2) a method for measuring the return of the venous flow in bone toward normal; 3) a predictable relationship between the patterns (with respect to time) of the reestablishment of blood flow and mechanical properties; and 4) the relationships between biomechanical and biochemical features and also between biomechanical features and calcification in fractures.

From the second set of studies, theme B, the results were as follows: 1) There are two naturally occurring "batteries" in dogs—one associated with the epidermis of skin and the other with the endosteum of bone—that become activated in response to an injury involving both bone and the surrounding tissues. 2) Skin-surface measurements of electrical voltage and current reveal different patterns associated with normal and delayed-healing fractures within the first 3 to 4 weeks after the injury. 3) Two different DC signals (1 microampere and 7

microamperes) applied during the first week after fracture seem to stimulate cell proliferative activity that leads to a significant acceleration of bone formation at the fracture site at 7 weeks after injury; two different cell populations or two different mechanisms may be involved in this response. 4) Comparison of five different electrical signals similar to those used clinically in fracture healing, as applied in long bones in dogs, demonstrate widely different features (amplitude, frequency, etc.), even though they have comparable clinical efficiency.

Our studies under theme B also suggest that none of these signals may be the most effective one for fracture healing. We expect that the knowledge about the influence of specific electrical parameters on the various features of fracture healing gained from our studies will be a useful contribution to the development of more reliable procedures for electrical therapy and prognosis in fracture healing.

Stimulation of Repair of Cortical Bone Transplants by Implantation of Piezoelectric Materials: A Development Study

G. V. B. Cochran, M.D., M.Sc.D.

Orthopaedic Engineering and Research Center, Helen Hayes Hospital, W. Haverstraw, NY 10993, and Surgical Research Service, Castle Point Veterans Administration Medical Center, New York 12511

Sponsor: VA Rehabilitation Research and Development Service; New York State Department of Health

Purpose—Stimulation of bone healing by microampere electric currents now is a recognized form of clinical treatment. For this purpose, various devices are available that aim to improve the healing of bone in problem cases, particularly for individuals with delayed nonunion. Typically, the stimulatory current is provided by a battery-powered device that delivers current to bone via electrodes or by an external electromagnetic device that induces currents in bone. Our purpose is to develop a novel approach to electrical stimulation of bone healing that employs microampere currents generated during physiological loading by a piezoelectric material that is incorporated as part of an internal fixation plate. Because piezoelectric materials produce an electrical charge under mechanical loading, we are thus developing an im-

plant that not only will stabilize bone but also will act as a self-generating electrical stimulation device that requires no separate power source.

Progress—To date we have designed and tested several versions of the "piezo plate." Initial tests showed that piezoelectric materials placed on the plate (so as to be in direct contact with bone) were not effective, probably because charge density over the surface was too low. Accordingly, we developed a device in which the piezoelectric material is sealed within the plate and all the charge developed is collected and delivered to bone via electrodes. During the past year we concentrated on electronic and mechanical design considerations necessary to create a version that could be used for trials in

large animals as a precursor to fabricating an initial model for clinical use.

Preliminary Results—Our animal tests so far have concentrated on the electrical output of prototype plates under functional conditions. These tests demonstrated that even on intact bone (such as in a late stage of fracture healing), the deformation produced by limited weightbearing is adequate to produce electric currents in the range known to stimulate osteogenesis, after necessary rectification and processing by miniature circuitry. Furthermore, we

showed that an implanted plate can be activated by external, low-power ultrasound to generate currents in an optimal stimulatory range. These developments hold promise for reducing the incidence of nonunion in problem fractures and may have potential for enhancing fixation of joint replacement prostheses.

Future Plans—The next phase of our study, "Testing of Design Parameters for a Prototype Piezoelectric Internal Fixation Plate," has been approved and involves testing the effects of the plate on bone healing in sheep.

Stress Analysis of Internal Fracture Fixation of Long Bones

Gary Beaupre, Ph.D., and Dennis Carter, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Internal fixation of fractured long bones using metal plates is a standard procedure for treating fractures that would be unstable if treated conservatively (e.g., splinted or casted). A possible complication resulting from internal fixation is refracture of the bone after the plate is removed. Some clinical studies have shown refracture rates to be as high as 20 to 25 percent.

Internal fixation is used on the long bones of both the lower (femur and tibia) and upper (humerus, ulna, and radius) extremities. Although exact figures for the number of fractures treated with internal fixation are not known, the popularity of this treatment mode is steadily increasing, particularly for treating forearm fractures where full range-of-motion in pronation and supination may be jeopardized with conservative treatment.

Refracture rates for the radius and ulna of 10 to 20 percent can be directly interpreted in terms of longer healing times with an associated loss of human productivity and increased medical costs for reoperations and prolonged physician treatment.

Although both vascular damage and mechanical stress shielding have been implicated as contributing factors leading to refracture, no studies have assessed mechanical stress shield-

ing using realistic mathematical models. All studies to date have assumed that no motion or slip occurs between the plate and the bone. However, numerous *in vitro* tests have shown that slipping between plate and bone occurs to a significant degree. By utilizing a nonlinear, mathematical model that permits slipping between plate and bone, we will be able to determine accurately the extent to which stress shielding is responsible for bone refracture.

We hypothesize that refracture after plate removal is caused by a combination of vascular damage and mechanical stress shielding. The importance of stress shielding has been overemphasized in all previous mathematical models because earlier studies have not incorporated realistic interface conditions. By including realistic interface conditions, we may arrive at a significantly different assessment of the amount of stress shielding. This in turn may have significant impact on future plate design and on current plate application techniques.

Progress—Using a nonlinear finite element model, we are capable of simulating slipping motion between the internal fixation plate and the fractured bone. Coulomb-friction contact elements are used to model the interface between the plate and bone and between the un-

derside of the screw heads and the plate. Screw tightness, friction coefficients, plate material, and plate-bone conformity will be studied parametrically.

An idealized plated bone model has been developed and analyzed for five possible *in vivo* loading conditions. The degree of mechanical stress shielding is shown to be intimately relat-

ed to how tightly the screws are applied. Loose screws produce minimal stress shielding; tighter screws produce more stress shielding. Estimates of screw tightness at plate explantation combined with the results of the present study suggest that previous predictions of stress shielding may be grossly in error.

Quantifying Fracture Healing by Impulse Transfer Functions

R. E. Jones, M.D.; M. G. Strauss, Ph.D.; R. W. Bucholz, M.D.; K. L. Lawrence, Ph.D.

Veterans Administration Medical Center, Dallas, TX 75216; University of Texas at Arlington, Arlington, TX 76019; University of Texas Health Science Center at Dallas, Dallas TX 75235

Sponsor: VA Rehabilitation and Research Development Service

Purpose—The need for a technique to quantify fracture healing and the role it would play in redefining clinical union, identifying delayed unions, and optimizing rehabilitation programs for accelerated fracture healing is well recognized in the orthopaedic community. Currently, only two tests to assess fracture healing are available—the roentgenogram and manual manipulation. Both are qualitative. Over the past 4 years, we have sought to develop a technique to quantify fracture healing in long bones via natural frequency analysis.

Progress—The natural frequencies of a structure are the frequencies at which the structure will vibrate with large amplitudes compared to other frequencies. Previous research has shown how the natural frequencies of the *in vitro* tibia change as the depth of a cross-sectional cut increases. The effects of the fracture location, callus size, and calcification process on the natural frequencies *in vivo*, and the relation of callus strength are being studied.

In the clinic, 26 patients with tibia fractures were followed. For the 24 normally healing patients, a correlation of $R = 0.74$ existed between the days postinjury and the normalized natural frequency. Two patients developed delayed unions and demonstrated different healing curves compared to the normally healing patients.

In order to establish the correlation between the natural frequencies and the strength

of the union, a dog model was established, and experiments were performed. Twenty-one male mongrel dogs underwent unilateral radial osteotomies. The forelimb was placed in a padded plastic spoon splint for 6 weeks postsurgery. Starting at 2 weeks postsurgery and at weekly intervals, each dog was placed in an elevated total body harness so that its limbs would hang clear of any surface; resonance testing was then performed on the radii of the unconscious dog. The impact transfer functions of both radii were obtained by impacting an instrumented hammer at the proximal lateral radius while an accelerometer was held against the anterolateral radius. Similar to the human study, the transfer function was obtained using a Fourier transform. After the designated healing time for a dog had been reached, the dog was euthanized, and both forelimbs were promptly removed. A 10-cm section from each radius was removed. The fracture site was at the mid-length. Each section was subjected to torsional failure.

Preliminary Results—The results of the torsional tests from 20 dogs showed an increase in torsional strength with increased time until approximately 100 days postosteotomy, at which time the torsional strength of the callus was twice the torsional strength of the intact radius. With the data from only 4 dogs analyzed, a trend appeared. As time progressed, the fracture radius natural frequency squared

divided by the normal radius natural frequency squared, also increased. The linear regression lines for the torsional strength versus time and that of the natural frequency versus time are very similar in slope. This implies that it would be possible to follow the course of healing in long bone fractures noninvasively by this tech-

nique and to identify abnormal deviations from the normal healing pattern sooner than present techniques allow. Clinical union may be quantitatively assessed *in vivo*. This method could also be used to determine what affects the rate of healing and to tailor an optimal rehabilitation scheme to accelerate fracture healing.

Altered Collagen and Wound Metabolism in Non-Healing Diabetic Ulcers

Roger E. Pecoraro, M.D.; John Olerud, M.D.; Mary Ann Riederer-Henderson, Ph.D.; Ernest Burgess, M.D.; Frederick A. Matsen III, M.D.; Craig Wyss, Ph.D.

Seattle Veterans Administration Medical Center, Seattle, WA 98108

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This project was designed to test the hypothesis that potentially correctable metabolic abnormalities may interact with ischemia, neuropathy, and infection to obstruct healing of diabetic ulcers. Subjects include diabetic and nondiabetic patients admitted to the Seattle VAMC Amputation Service who may require lower extremity amputation as a result of diabetes and/or vascular disease. We will test whether recent poor glycemic control, abnormal ascorbic acid metabolism, altered zinc availability to injured tissue, and increased nonenzymatic glycosylation of dermal collagen are associated with and potentially responsible for failure of wound healing that leads to amputation in diabetic individuals.

The objective of these cumulative investigations is to identify metabolic abnormalities that are potentially correctable and that may contribute to limb loss and wound failure in diabetic individuals.

Progress—Glycemic control in diabetic patients is being documented by measurements of fasting plasma glucose and glycosylated hemoglobin. Ascorbic acid levels are determined in samples of plasma from all patients and in leukocytes and dermal tissue from selected patients, measured by high-performance liquid chromatography. Zinc levels are being measured in samples of plasma, leukocyte, and wound tissue by atomic absorption spectrophotometry. Collagen fractions are extracted from skin and wound tissue specimens from amputated limbs

for subsequent measurement of the extent of glycosylation of collagen. Nutritional status is being evaluated by a laboratory panel of nutritional indicators. Vascular status of diabetic and nondiabetic amputation subjects is being documented by standardized measurements of limb transcutaneous oxygen tension (TcPO₂) and segmental doppler blood pressures.

To date, we have studied 79 diabetic individuals who have been candidates for or who have actually received limb amputations. A total of 49 nondiabetic amputees, all with peripheral vascular disease, were enrolled. In addition, many of the biochemical and vascular measurements were standardized in 10 healthy nonsmoking elderly males without diabetes or vascular impairment. Vascular and plasma metabolic measurements have been made in 150 control diabetic individuals admitted to the same hospital but who have not had amputations or lower extremity ulcers.

Preliminary Results—Both diabetic and nondiabetic amputation patients have shown significant deficiencies in plasma zinc and ascorbic acid levels. Preliminary analysis of tissue extracts suggests that ascorbic acid is concentrated in dermal tissues at sites of cutaneous ulceration. Further studies are in progress to determine if tissue concentrations of ascorbate and zinc in these patients are suboptimal for adequate wound healing. Experimental iatrogenic microwounds have been inflicted on the limbs of a volunteer subgroup of patients 7 days

before amputation; histologic evaluations of those tissues, in progress, will provide a semi-quantitative independent index of cutaneous wound healing to correlate with the metabolic parameters.

We confirmed the observation that many

patients with diabetes, unlike nondiabetics requiring amputation resulting from advanced peripheral arterial disease, often fail to heal limb ulcers despite adequate cutaneous oxygen diffusion.

Morphological and Clinical Studies of Microwounds in Ischemic Human Tissue

John Olerud, M.D.

School of Medicine, University of Washington, Seattle, WA 98195

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to study in a systematic fashion morphological and clinical features of small standardized wounds created on the lower extremities of normal elderly subjects and patients with severe peripheral vascular disease (PVD) necessitating amputation.

Progress—We developed a standard human wound model for evaluating 12 morphological events of repair. The events include presence of scab, epidermal migration, epidermal closure, epidermal hyperplasia, amount of stratum corneum, stratum granulosum, fibrin neutrophiles, monocytes, fibroblasts, collagen, and capillaries.

Wounds from 18 diabetics, 13 patients with PVD, and 11 normal subjects were fully processed and evaluated. The results were entered on a computer database, and preliminary data analysis was done. Additionally, we developed a timetable of immunohistochemical events of healing in elderly normal subjects using 10 antibodies relevant to the repair process (filaggrin, keratin, *Ulex europeus* I, laminin, type IV collagen, type I collagen, type III collagen, vimentin, thrombospondin, and factor VIII). This wound model and timetable will be used for comparative studies of normal subjects and patients with PVD and DM.

Transcutaneous Oxygen Tension as Predictor of Wound Healing

Frederick A. Matsen III, M.D.; Ernest M. Burgess, M.D.; Craig R. Wyss, Ph.D.; Richard M. Harrington, M.S.

Limb Viability Laboratory, University of Washington, Department of Orthopaedics, Seattle, WA 98195

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Transcutaneous oxygen tension is the surface oxygen tension measured with a small heated sensor sealed to the surface of the skin. Cutaneous heating induces local hyperaemia in the skin under the sensor and allows measurement of the potential for oxygen delivery in relation to metabolic needs. The oxygen that diffuses through to the surface of the skin is that delivered in excess of local metabolic needs. This year our group published reports on the relation between transcutaneous oxygen tension measurements ($TcPO_2$), ankle systolic blood pressure measurements (ABP), and the clinical outcome of both vascular surgery and

amputation surgery.

Preliminary Results—Both $TcPO_2$ and ABP were measured before and after 53 vascular procedures performed to relieve limb-threatening ischemia. In the patients without diabetes, those with post-surgical ABP greater than 75 mmHg or $TcPO_2$ greater than 20 mmHg showed resolution of the clinical symptoms within 60 days after surgery. All patients falling below these levels underwent subsequent limb amputation.

Diabetic patients had different results, with many having high ABP in conjunction

with low TcPO₂. This was attributed to a high incidence of calcific medial stenosis leading to elevated ABP measurements. The clinical outcome of vascular surgery on diabetic patients was uncorrelated with the postsurgical ABP and poorly correlated with postsurgical TcPO₂. Those with postsurgical TcPO₂ below 20 mmHg all had unfavorable outcomes, but many with higher values also sustained slow healing of ulcers, persistence of rest pain, and/or limb amputation.

In the study of 284 amputation surgeries, TcPO₂ and ABP were measured within the 2 weeks before surgery. The amputations were performed at levels selected by clinical criteria only. The surgery was classified a success if the amputation wound eventually closed and healed, even if it required a long period and/or local debridement. For both diabetic and nondiabetic patients undergoing either foot or below-the-knee amputation, there is a signifi-

cantly increasing risk of amputation failure as presurgical TcPO₂ values decrease. Thirty percent of surgeries on limbs with measurements in the range 11 to 20 mmHg failed; more than 60 percent failed on limbs with measurements less than 10 mmHg. For above-the-knee amputations, presurgical TcPO₂ had no predictive value in the surgical outcome.

Presurgical ABP appeared to have predictive value only for patients without diabetes. Among diabetic patients, calcific medial stenosis appears to interfere with ABP measurements. Even among nondiabetic patients, there were a large number (greater than 50 percent) with undetectable pulses but sufficient limb blood supply to heal an amputation.

We conclude that presurgical TcPO₂ measurements are useful as an addition to or replacement for ABP in evaluating the outcome of vascular and amputation surgery.

Enhancement of Ulcerated Tissue Healing by Electrical Stimulation

L. Vodovnik, D.Sc.; A. Stefanovska, Dipl.Eng.; R. Turk, M.D.; H. Benko, P.T.; M. Malezic, Dipl.Eng.; V. Kosorok, M.D. Electrical Engineering, E. Kardelj University; University Rehabilitation Institute; Jozef Stefan Institute, 61000 Ljubljana, Yugoslavia

Sponsor: National Institute for Handicapped Research, Washington, DC; Slovene Research Community, Ljubljana, Yugoslavia

Progress—Pulsed or DC electrical currents have been successfully applied in healing indolent wounds. In our preliminary experiments, dual-channel stimulation was applied to spinal-cord-injured patients with decubitus ulcers, to postamputation wounds, and to ulcus cruris. After encouraging results on 30 patients, a study was started on 10 spinal-cord-injured patients with decubitus ulcers, which had developed over a period of several months. Stimulation was started 1 week after admission to the Rehabilitation Institute. Two channels of biphasic stimulation with tetanizing currents were applied through four electrodes across the wound. The stimulation parameters were a frequency of 40 Hz and a pulse width of 250 microseconds. The amplitude (up to 50 mA) was adjusted to achieve minimal muscle contraction when feasible. Stimulation was applied twice

daily for 20 minutes. Once weekly the volume of the wound was measured by approximate measurements of surface and depth, the wound was photographed, and wound tissue samples from the center, the periphery, and from eventual pockets were taken for bacterial tests.

The size of all wounds decreased after stimulation. The initial healing rate (cm³/day) depends on the initial wound volume (cm³). The healing rate per 1 cm³ initial wound volume ranged between 0.01 and 0.02 per day. Thus, an initial wound of 200 cm³ started to heal with a rate of about 2 to 4 cm³/day, the rate decreasing exponentially with time. The time constant of healing is thus between 50 and 100 days. Bacterial tests had previously produced no consistent relation between the healing process and changes in the types of bacteria.

Acceleration of Fracture Healing Electrical Fields

Carl T. Brighton

University of Pennsylvania, Philadelphia, PA 19104

Sponsor: *National Institutes of Health*

Purpose—The object of the proposed research is to continue investigating the effects of applied electrical fields on the acceleration of fracture healing in laboratory animals. The proposed research was designed: 1) to determine the optimum parameters of applied (exogenous) electricity for accelerating fracture healing; 2) to determine the role of stress-generated (endogenous) electricity in fracture healing; and 3) to determine the mechanism of electrically induced osteogenesis at the cell level.

Methods to be used include the comparison of the osteogenic response of *in vitro* fetal rat tibia and *in vivo* healing rabbit fibula to constant DC, various pulsed unidirectional electric fields, and various electromagnetic fields. Os-

teogenesis and bone healing will be evaluated by incorporation of tritiated thymidine, Ca45, and ³⁵SO₄ as well as by maximum resistance to bending as determined by an Instron Testing Machine. Stress-generated potentials will be measured in fracture calluses. Origin of stress-generated potentials will be evaluated by altering collagen in tendon biochemically. The mechanism of action of electrically induced osteogenesis will be sought by determining: 1) PO₂ and pH changes in the vicinity of a cathode; 2) changes in surface of cell membrane; 3) mitochondria release of calcium; 4) cellular proliferation and migration; and 5) collagen and proteoglycan biosynthesis and processing.

Biomechanics of Metastatic Defects in Bone

Wilson C. Hayes

Beth Israel Hospital, Boston, MA 02215

Sponsor: *National Institutes of Health*

Purpose—Advances in the palliative treatment of patients with established metastatic malignancies have not only prolonged patient survival but have also increased the incidence of bony metastases and subsequent pathological fractures. Thus, prevention and effective treatment of fractures associated with metastatic defects in bone have become increasingly important aspects of the care of cancer patients. Unfortunately, there are currently available only the crudest of clinical guidelines for assessing the increased fracture risk associated with metastatic lesions in bone. Therefore, the appropriate time for prophylactic stabilization of impending fractures is not known. This investigation will be directed in the long term to the development of comprehensive biomechanical guidelines for the orthopaedic assessment and treatment of metastatic defects in long bones, the proximal femur, and the spine.

A four-phase staged approach will be used.

In Task I, we will conduct retrospective radiographic reviews of patients exhibiting metastatic lesions in those regions and will determine the most frequent sites and approximate shapes of the lesions. As part of this task, we will also develop improved diagnostic imaging procedures for the description of lesion geometries. In Task II, we will determine *in vitro* the strength reductions associated with simulated defects in long bones, the proximal femur, and the spine. In Task III, we will use finite element modeling of defects in these regions to provide a theoretical framework for interpreting the experimental results and assessing the sensitivity of the fracture risk predictors to individual patient variations. In Task IV, we will combine these findings by developing structural predictors of fracture risk for individual patients with particular lesions. Biomechanical guidelines appropriate for each skeletal region will be developed and tested retrospectively in

clinical populations. These guidelines should represent a significant improvement in the

orthopaedic care of patients with metastatic defects in bone.

Management of Burn Injuries

J. H. Evans, Ph.D.; J. M. Courtney, Ph.D.; J. D. S. Gaylor, Ph.D.

Bioengineering Unit, Regional Burns Unit, and Plastic and Oral Surgery Unit, University of Strathclyde, G4 ONS Glasgow, Scotland

Sponsor: *Dow Corning Corporation*

Purpose—Work continues on providing a broad-based better understanding of the burn wound and hypertrophic scar and on improving the management of burned patients. Currently, research is directed to assessing burn depth, determining mass and energy loss from the burn wound, developing synthetic dressings, *in vitro* expansion of autologous epithelium, and the treatment of hypertrophic scars with silicone gel and pressure garments.

Progress—A thermographic technique, employing a low-cost and convenient pyroelectric Vidicon camera, is based on previous work using an animal model along with a mechanically scanned detector.

Laboratory and clinical investigations are being conducted on novel burn dressings and on candidate materials including silicone-based

materials and hydro-gels. Consideration is being given to mechanical strength and conformability, mass and energy flux, bacterial control, and drug release. Electromagnetic enhancement of the rate of expansion of epithelium is being studied *in vitro* to provide a clinically acceptable source of autologous skin for the management of the severely and extensively burned patient.

Preliminary Results—A substantial trial has demonstrated that a silicone gel dressing can make a significant contribution to the rate of resolution of hypertrophic scars. On many sites, particularly the face and hands, it is more manageable and better tolerated than is therapy based on pressure. No significant complications have been observed in a trial of 150 patients.

Quantitative Evaluation of Nerve Repair

Vincent R. Hentz, M.D.; Joseph Rosen, M.D.; John Wikswo, Ph.D.; Kenneth Cummins, Ph.D.; Gordon Abraham, M.S.
Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The treatment of peripheral nerve injuries rarely results in recovery of function adequately approaching that before the injury. In dealing with these injuries, the physician faces two major problems. First, the lack of objective methods for assessing the extent of peripheral nerve injury or the extent of regeneration in previously injured nerve compels physicians to rely on subjective criteria in making clinical decisions regarding the management of these injuries. Second, present methods of peripheral nerve repair, even those employing modern microsurgical techniques, rarely result

in regeneration sufficient for full functional recovery. A number of adjuncts to traditional repair methods offer the promise of increased or directed regeneration, but the effectiveness of these new approaches needs to be assessed objectively.

The development of a simple method for evaluating the extent of a nerve injury will help the physician make objective decisions regarding the timing and type of care of the injured nerve. The use of the appropriate modality for the treatment of nerve injuries will enhance and speed the regenerative process and

will lead to fuller recovery of function.

Purely mechanical (suture) methods of reapproximating peripheral nerves result in very limited functional axonal regeneration. It is thought that this is due primarily to scar formation at the repair site, which prevents proximal axons from crossing the repair site and establishing functional connections. We have been studying sutureless repair methods that use biodegradable wraps that provide total circumferential alignment of the nerve, block scar invasion at the repair site, and improve the milieu for axonal regeneration. The preliminary results of our early investigation indicate that none of the purely mechanical alignment techniques hold any significant advantages to regeneration. Regeneration is being assessed using electrophysiological methods that estimate the number and velocity distribution (DCV) of axons both proximal and distal to the repair site. The analysis methods presently used require involved mathematical computation and must be performed off line. Such evaluation methods are currently inappropriate for clinical use by physicians.

This project is based on two fundamental hypotheses. First, we feel that nerve function following injury, or axon regeneration following repair, can be reliably, quickly, and safely evaluated by electrophysiological methods that estimate the number and health of the axons crossing a focal lesion or repair site. For this tool to be generally applicable, it must be appropriate for both noninvasive and invasive (intraoperative) studies. Second, to enhance nerve regeneration in any significant and reliable fashion, modern mechanical repair methods will have to be coupled with other modalities that intrinsically influence the rate and/or direction of axonal regeneration (tropic factors), that improve the axonal environment at the repair site (pseudoperineurial barriers), or that decrease the effect of scar formation.

Progress—We are currently developing a simple technique for characterizing nerve function and regeneration at the repair site. This method estimates the number of axons that cross a focal lesion (or repair site) and their dis-

tribution of added conduction delays. This approach requires considerably less computation than DCV analysis. We are also investigating the possibility of using magnetic recording and/or stimulating techniques for intraoperative evaluation of exposed nerve bundles. By employing magnetic coupling for recording, the practical problems of mechanical nerve damage, stimulus artifact, and operating-room ground loops will be minimized. The resulting signals, which reflect longitudinal current in the axons, can be analyzed by any of our methods of nerve evaluation. Initial experiments on magnetic measurement of action currents from rat sciatic nerve, performed in cooperation with John Wikswo, Ph.D., of Vanderbilt University, have been quite promising. Innovations by Dr. Wikswo permit measurements at room temperature using inexpensive equipment.

Preliminary Results—During this project we have compared the use of a biocompatible, biodegradable “pseudoperineurial barrier” to standard microsutures in several primate nerve repair and nerve graft models. In spite of intraoperative technical problems with the first-generation pseudoperineurial barrier, the initial results from postoperative electrophysiologic assessments of the number of axons having regenerated across the repair site indicate that the barrier does as well as or better than standard suture repair methods.

There is mounting evidence that an autoimmune reaction follows destruction of the perineurial blood-nerve barrier during nerve injury. We have studied the effects of an immunosuppressive agent, Cyclosporin-A, in decreasing the initial inflammatory response associated with nerve injury in a rat model. Preliminary histologic results indicate a significant diminution of inflammatory cells about the repair site. Early electrophysiological studies indicate some enhancement of regeneration. In contrast, studies of the effects of the ability of electromagnetic fields to enhance regeneration have not produced significant results.

Encouraging results have been obtained using simulated data to test the model for characterizing focal conduction delays that occur at

the site of nerve injury or repair. The programs will soon be adapted to run on portable evoked potential equipment, and human intraoperative assessments of nerve injuries will soon follow.

Several modifications in the neuromagnetic system have allowed the acquisition of reliable

data from primates and rats. These data indicate that the neuromagnetically derived waveforms can be processed exactly like the electronically recorded counterparts. The development of an openable clip-on toroid will permit human studies to begin soon.

Nerve Coupler—Sutureless Peripheral Nerve Repair at the Fascicular Level

Joseph Rosen, M.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Current methods of peripheral nerve repair often result in unsatisfactory restoration of function of nerves. Factors at the repair site that can contribute to these poor results include: 1) poor alignment of the repair site by suture methods; 2) ingrowth of surrounding scar tissue that blocks the repair site; and 3) outgrowth of nerve tissue from the repair site into surrounding tissue with consequent neuroma formation.

The importance of our study lies in its potential for improving the current state of peripheral nerve repair. Peripheral nerve damage associated with trauma to bones, tendons, and other structures occurs in approximately 30 percent of extremity trauma. Nerve injuries prevent successful rehabilitation more than any other form of trauma. Motor dysfunction, loss of tactile discrimination, sympathetic dystrophy, and postregenerative pain can greatly impair self-care and other tasks of daily life, leading to long-term disability. Improved nerve repair would theoretically improve veterans' quality of life following nerve repair.

Present methods of peripheral nerve repair by suture are based on an anatomical approach that attempts to reestablish continuity of the multiple layers of nervous tissue. In suture repair, either the epineurial or perineurial layers of connective tissue are reconnected by sutures to promote healing of the nerve. In suture repair, the discrete tissue layers are obliterated by scar tissue at the repair site. An alternative to this anatomical approach is a cellular approach involving the construction of an artificial perineurium. The perineurial layer di-

vides the nerve into two distinct cellular environments. The intrafascicular Schwann cells, axons, and endoneurial fibroblasts compose the nerve's regenerating unit. The cellular components of the extrafascicular environment are responsible for the fibrous reaction to injury.

In a number of previous papers, the investigator has developed and described tubes that reconstruct the perineurium. This sutureless method of nerve repair (fascicular tubulization) allows the nerve to reestablish the perineurium naturally. Histology and electrophysiology have shown collagen tubes to be an effective repair method in rat monofascicular and cat multifascicular models. Bioresorbable polyglycolic acid (PGA) tubes were shown to be successful in the rat monofascicular model by qualitative and quantitative histology. No prior methods of nerve repair have used this fascicular tubulization technique.

The results of peripheral nerve repair may be improved by developing a better method to approximate the transected ends of a nerve. The development of a device that couples the ends of the nerve together without sutures might improve on the poor results of suture repair. The "nerve coupler" will precisely approximate the ends of a transected nerve fascicle. This will improve the alignment at the repair site. The device will also act as a barrier to the ingrowth of scar tissue from outside the perineurium. It will serve to block the outgrowth of intrafascicular nerve tissue into the extrafascicular space.

Progress—The first objective of this pilot study

was to determine a satisfactory design and material for the nerve coupler. Prototype plexiglass couplers and bioresorbable polyglycolic acid (PGA) couplers were studied in the monofascicular rat peroneal nerve. These 1- to 3-month short-term studies were designed to determine how effectively the coupler maintained the integrity at the repair site during regeneration. These studies also compared coupler repair with controlled perineurial suture repairs. Gross and microscopic reactions to coupler materials were evaluated. Repair site organization was assessed by histology. The results of this pilot study will be used to modify the design of the nerve coupler.

Preliminary Results—Trials of plexiglass couplers in two animals demonstrated simple application of the coupler and excellent nerve alignment on gross visual examination. Histo-

logical evaluation showed excellent alignment and minimal cellular reaction at the coupler repair site. Studies of 1, 2, and 3 months' duration using PGA couplers again showed simple application of the coupler and excellent gross alignment at the sutureless repair site. Microscopic evaluations of 1- to 3-month animals revealed fair to excellent organization at the coupler repair site and minimal to moderate reaction to coupler material.

Future Plans—Our next goal is to obtain VAMC RAG funding to continue our studies of the nerve coupler in the rat peroneal nerve. We would like to perform long-term studies to evaluate repairs using quantitative histology and electrophysiology. We would also like to evaluate new designs and new materials for the coupler in future studies.

Evaluation of Tubular Internal Fixation Plate for Fracture Management

Savio L-Y. Woo; Richard Coutts, M.D.; David Amiel, Dip.Ing.; Steven Garfin, M.D.; Wayne Akeson, M.D.

Veterans Administration Medical Center, La Jolla, CA 92103 and University of California, San Diego, CA 92103

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The overall objective of this project is to determine whether significant advantages can be obtained from internal fixation of diaphyseal fractures using plates with improved design. Specifically, our goal is to test the newly developed design criteria. That is, moderate bending and torsional plate rigidities are needed for early immobilization to achieve fracture healing without bone shortening and/or angulation, and low plate axial rigidity is desirable to minimize stress (strain) shielding of the underlying bone during the postunion remodeling process. A new plate with a tubular cross-section is made of stainless steel filled with polyethylene. This plate has the aforementioned desired rigidity characteristics and will be used in a canine unilateral midshaft femoral osteotomy mode. A traditional solid stainless steel plate of identical external geometry will be used in a separate series of animals with similar osteotomy. In addition, it is also our goal to test whether such a low axial rigidity plate can

prove to be advantageous to the recovery of full structural properties of the underlying bone following plate removal.

Progress—At present, the evaluation of the bone lying beneath both the traditional solid stainless steel (control) and the new tubular (experimental) plates is being performed using X-ray, geometric measurements, histomorphometric measurements, and biochemical techniques. Specifically, a comparison is being made between the actual physical properties of bone and the structural and mechanical properties obtained by biomechanical bending and by axial and torsional testing.

Preliminary Results—Histomorphometric data have shown that on the average, bone porosity is higher for the control solid stainless steel plate, whereas there is an increase in new bone growth and less porosity for bone lying beneath the experimental hollow plate. This informa-

tion correlates well with the bioengineering tests performed. With further comparison and study of these test results, we hope to provide

more insight into the problem of localized osteopenia that occurs with the use of internal fixation plate systems.

Biomechanical Considerations of Metal and Composite Materials for Bone Fracture Fixation Plates

Savio L-Y. Woo ; Wayne H. Akeson; Richard D. Coutts

University of California, San Diego and San Diego Veterans Administration Medical Center, La Jolla, CA 92103

Sponsor: VA Rehabilitation Research and Development Service

Progress—This study, together with others, refutes the necessity of extremely high plate bending and torsional rigidities (absolute immobilization of the fractured bone ends) for union. Plates with significantly less rigidities, and applied without “compression”, were able to achieve equivalent and better bone healing with the aid of callus formation. The results of this series of experiments confirm that osteonal bone union is slow and mechanically inferior to callus union.

The design criteria developed by our laboratory—that is, moderate bending and torsional rigidities (to provide adequate but not “rigid”

fixation of fractured bone for formation of periosteal callus and for union) together with the low plate axial rigidity (to allow the healed bone to share a larger portion of the physiological stresses to reduce the instances of stress-protection osteopenia)—may be an ideal compromise between investigators who advocate rigid internal fixation systems and those who advocate flexible ones. A tubular cross-sectional stainless steel plate may be an optimal design for such a less rigid fixation plate system. Other materials and designs following these guidelines also should be pursued.

VIII. Properties of Muscle

A. General

Cross-Talk Between Myoelectric Signals of Adjacent Muscles

Roberto Merletti, Ph.D., and Carlo J. De Luca, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company; Politecnico di Torino, Torino, Italy*

Progress—Electrical stimulation techniques have enabled us to quantify the cross-talk or interface between adjacent muscles. The presence of cross-talk is a problem for myoelectric controls such as those used in prostheses and for analyzing the functional performance of antagonist and synergist muscle coactivation. Because voluntary control is goal-oriented, any effort to move a joint results in the activation of a number of synergistic and antagonistic muscles. The surface myoelectric signal recorded from one muscle may be affected by the electrical activity of its neighbor. This issue has never been investigated in quantitative detail.

Electrical stimulation of a nerve branch produces more selective control of an individual muscle than that achieved by a voluntary contraction. Therefore, electrical stimulation provides a suitable method of investigating the

cross-talk between individual muscles. Surface myoelectric signal readings were taken from directly stimulated and adjacent muscles. The four-bar electrode developed for conduction velocity measurements (described in our 1984 Activities Report) allows us to verify that the myoelectric signal does not result from adjacent muscles.

Preliminary Results—Preliminary results demonstrate that the myoelectric signal generated by the electrical activation of the tibialis anterior muscle is present on the peroneus brevis muscle (5-15 percent) and on the soleus muscle (3-8 percent). These findings clearly reinforce the need to develop appropriate techniques when selectivity is an important experimental requirement.

Topical Anesthesia and Muscle Hypertonicity

Claire McCarthy, M.S. and Carlo J. De Luca, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Progress—Some form of muscle rigidity (spasticity) affects at least 6 million people in the United States. The estimated annual cost to our society for health care and the reduction of manpower in the work environment exceeds \$20 billion.

We have been experimenting with a noninvasive technique for rehabilitating patients who have suffered from strokes or head injuries.

This technique entails the application of a topical anesthetic to selected skin areas on the affected limbs. We have observed that these applications are associated with notable decreases in muscle rigidity and often with increased limb mobility. The short-term effects (within 1 hour after application of the topical anesthetic) have been studied in 80 patients; the long-term effects are currently under investigation. To

date, we have collected various data concerning kinematic parameters, reflexes, and expressions of functional capabilities on 12 patients with stroke and head injury.

One of the electrophysiological tests made on the patients consisted of measuring the muscle response induced by an electrical stimulus to the nerve supplying the gastrocnemius and soleus muscles in the leg. These measurements were taken at various intervals during a 1-month segment in which the patients had the topical anesthetic applied to their legs 3 days per week and were requested to perform an exercise program while the muscle rigidity de-

creased. This test was intended to measure the sensitivity of specific neuronal connections in the spinal cord and to observe whether they were modified as a function of the therapy program. The data analyzed to date suggest that the topical anesthetic has an effect on the muscle response that is similar to that previously observed in healthy subjects. It now remains for us to study the time progression of the effect as a function of the exercise program.

External interest in this project continues to be high. We continue to receive many requests for information about our work from patients and clinicians.

Surface Electrode Design

L. Donald Gilmore, A.B.E.E.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Progress—Clear and accurate detection of myoelectric activity from the surface of a muscle is a basic prerequisite for the detailed evaluation of muscle behavior. Most of our laboratory and clinical evaluations require some type of surface electrode to observe muscle signal properties such as amplitude, spectral shift, conduction velocity, and location of motor points. These parameters are useful in evaluating the status of an actively contracting muscle.

During the past few years, we have developed several configurations of active surface electrodes that do not require the use of conductive paste or gels. Each electrode configuration is based around an electronic circuit containing a high-impedance, low-noise, differential preamplifier housed in small, rugged, epoxy

packages. (A detailed description of the active surface electrode concept appears in the NMRC 1983 Activities Report.) We have found that these surface electrodes have the mechanical and electrical stability necessary for reliable and consistent low-noise myoelectric recordings. We now use these "standard" electrodes in a vast majority of our laboratory experiments, such as those concerning muscle fatigue.

Currently, the circuitry and mechanical configuration of our active surface electrode designs are being reviewed. Fabrication using hybrid or monolithic circuit techniques is being considered for further standardizing our electrode designs. Designing our surface electrodes for production procedures using current standard manufacturing technology would enable other laboratories to use our surface electrodes.

Multi-Channel Surface Electrode Array

L. Donald Gilmore, A.B.E.E.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Progress—Recently, two Boston University students working under the guidance of the NeuroMuscular Research Center and the Liberty

Mutual Research Center in Hopkinton, MA, have designed and constructed a prototype electrode array for detecting myoelectric signals.

The array consists of 16 button electrodes arranged in a 4 x 4 grid, covering an area of 60 mm². Signals from the electrode contacts can be combined in a variety of patterns, making this configuration suitable for many recording applications. The array may prove useful for

measuring conduction velocity and muscle fatigue parameters, for locating innervation zones, and for studying cross-talk among different muscle groups. Research work focusing on these potential applications is continuing at our laboratory.

B. Muscle Contraction

The Myoelectric Signal Decomposition Technique

Carlo J. De Luca, Ph.D., and Daniel W. Stashuk, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Progress—During the past several years, a procedure for studying the individual behavior and interaction of populations of concurrently active motor units has been developed and refined. Information is obtained by analyzing, in detail, the electrical signal that is generated in a muscle when it contracts. This signal is called the myoelectric signal. In our technique, myoelectric signals are detected by a specialized needle electrode. The procedure has primarily three components: signal acquisition, decomposition, and the analysis of individual motor-unit information.

Work has continued on further development and refinement of the motor unit analysis procedure. These efforts have been concentrated on increasing the speed and ease with which the analysis can be performed. Improvements of this nature will further advance the clinical practicality of the technique and will facilitate physiologically based research. To this end, the use of alternate needle electrodes and signal de-

composition techniques has been preliminarily studied. Program revisions and user manuals have been written to make the analysis system more readily accessible to investigators at the NeuroMuscular Research Center.

Using the motor-unit analysis technique, investigations into a number of interesting motor control questions are currently in progress. The study of the phenomenon of synchronization of motor-unit activity has been refined and extended. The effect of specific movement disorders on motor control schemes is being examined. Changes in motor-unit excitability due to the loss of skin sensory input are analyzed. Also of interest is the accuracy with which different muscles can follow a prescribed force trajectory and the implications of this to motor control.

The details of the technique were presented in June at the Second International Symposium of Computer EMG Applications in Monte Carlo, Monaco.

Control of Antagonist Muscles

Carlo J. De Luca, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Progress—We are attempting to clarify the control mechanism of antagonist (opposing)

muscles during the initiation and continued production of force associated with voluntary

contractions. Our study focuses on the flexor pollicis longus and extensor pollicis, the two sole activators of the distal thumb joint.

During isometric contractions, the firing rates of motor units within a muscle were greatly cross-correlated with essentially zero time-shift with respect to each other. This behavior has been termed the common drive. Common drive was also found to be present among the motor units of the agonist and antagonist muscles during voluntary coactivation to stiffen the interphalangeal joint. This observation suggests two interesting facts: 1) the common drive mechanism has a component of central origin; and 2) the brain may control the motor units of two (and possibly more) muscles

as if they are one when the muscles are performing the same task.

We have suggested a control scheme to explain the behavior of the motor units in both muscles during varied contraction modalities. It consists of reciprocally organized flexion and extension commands originating from the brain along with a common coactivation command to both muscles. Both interact with the inhibitory and excitatory influence of sensory information that is supplied by specialized sensors within the muscle.

Articles describing our work in this area were published in *Brain Research* and the *Journal of Experimental Biology*.

Motor Control in Movement Disorders

Janet Sullivan, B.S.; Joseph F. Jabre, M.D.; Daniel Stashuk, Ph.D.; Carlo J. De Luca, Ph.D.
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: VA Rehabilitation Research and Development Service; Liberty Mutual Insurance Company

Progress—The myoelectric signal of normal subjects has been decomposed into its constituent motor units, and their behavior has been analyzed. The known statistical behavior of motor units from normal subjects can be used as the basis for comparing the motor-unit activity observed in subjects with different movement disorders. It is hoped that useful information can be gained from studying motor-unit behavior in impaired subjects.

Samples of the myoelectric signal from the first dorsal interosseous muscle of the hand in several patients with different movement disorders have been collected. The presence of the common drive is of considerable importance in this study. Also of importance is the relationship between motor-unit firing rates as a func-

tion of force output and as a function of recruitment threshold. Because there is considerable time and effort involved in the complete analysis of a patient's data, efforts were focused on a patient with syringomyelia or liquid-filled cavity in the spinal cord.

It has been observed that common drive is preserved in the syringomyelia patient with clinical confirmation of deafferentation. Also, the firing rate of a motor unit, as a function of the force of recruitment, appears to be compressed when compared to similar contractions of a normal subject. A preliminary evaluation of the data obtained from the ulnar neuropathy and cerebellar atrophy patient suggests the presence of common drive.

Synchronization of Motor Unit Discharges

Jerry Scala, B.S.; Carlo J. De Luca, Ph.D.; Daniel Stashuk, Ph.D.
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: Liberty Mutual Insurance Company

Purpose—Synchronization is defined as the tendency for two or more motor units to fire

with a preferred latency more often than would be expected if motor units functioned independ-

ently. In order to make accurate statements regarding the interactions of active motor units, decomposition and statistically robust analysis techniques must be employed. The goal of this work is to present irrefutable evidence indicating that synchronization is indeed a property of concurrently active motor units.

Progress—A computer algorithm was created that calculates the synchronization ratio—that is, a numerical estimate proportional to the amount of synchronous behavior among pairs of concurrently active motor units. During the past year we have revised this algorithm to determine the statistical significance of the results. Histograms of the relative latency between firings of two different motor-unit action potential trains are constructed. If it is assumed that the two trains act independently, the number of firings in each bin can be mod-

eled as a Poisson distributed random variable. Consequently, we can determine the number of firings required in a bin to state at a prescribed level of confidence that the motor units are not contracting independently and that synchronization has occurred. Synchronization ratio measurements based on significant bins, defined with a 95-percent level of confidence, are used to quantify synchronous behavior.

The results indicate that synchronization exists in all 14 different muscles we have examined. We have also begun to examine the frequency and extent of synchronous behavior during recruitment of new motor units, between different-sized motor units, and across antagonist and synergist muscles.

It is hoped that these new results can be applied toward devising a clinical technique for use in the evaluation of neuromuscular dysfunction.

Force Output of Muscles During Voluntary Isometric Contraction

G Gomez, B.S.; Daniel Stashuk, Ph.D.; Carlo J. De Luca, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Progress—Through this study we have investigated how smoothly different muscles produce a prescribed force. Different muscles use different control schemes to produce force. For example, recruitment is the major mechanism for generating force between 40 and 80 percent of maximal force in the deltoid, whereas rate coding of firing rates plays the major role in the first dorsal interosseous muscle of the hand. We have begun to investigate how these different control schemes affect the smoothness of the force output produced.

Muscles are incapable of producing a purely isotonic constant force contraction even under isometric conditions. In our previous work we have shown that the firing rates of motor units have a common fluctuation that os-

cillates at 1-2 Hz. These firing-rate fluctuations are causally related to similar fluctuations in the force output of the muscle.

Through analysis of the power spectrum of the force output we have begun to investigate the frequency and amplitude of modulation of the firing rates and the force output. The smoothness of the force output will be described through linear regression analysis and normalized errors. Comparisons between different muscles at different force levels and with various types of isometric contractions will be made using the standard T-test.

Results of this study will provide an indication of how efficiently the neuromuscular system produces isotonic force output.

Sensorimotor Interaction in Motor Unit Control

Isao Matsuzawa, M.D., Ph.D.; Francesco Felici, M.D.; Carlo J. De Luca, Ph.D.
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company; Nippon Medical School, Tokyo, Japan*

Progress—For several years we have been investigating a procedure whereby we apply a topical anesthetic to the skin and observe dramatic modifications in the response of the underlying muscles. Our work has shown that this procedure is particularly beneficial to stroke and head-injury patients who have muscle rigidity and a limited range of movement in their joints. In order to more fully understand the underlying physiological modifications, we have undertaken a study to investigate the effect on the individual motor units in the involved muscles. Our current work is limited to studying the changes that occur at the threshold of recruitment of motor units when the nearby skin is desensitized.

Myoelectric signals are detected from a hand muscle, the first dorsal interosseous, in healthy men during an increasing and decreasing

force output, while a specialized needle electrode is inserted into the muscle. Motor-unit recruitment patterns are determined by the signal decomposition previously described. The effect of skin desensitization is examined by comparing the motor-unit recruitment threshold before and after the application of the topical anesthetic.

Preliminary Results—Preliminary indications are that the recruitment thresholds of larger motor units decrease and the recruitment thresholds of smaller ones increase. This modification suggests that inputs to the larger motoneurons and those to the smaller ones are not qualitatively similar in man. This preliminary result also explains the increase in the force output observed in stroke patients.

Automatic Decomposition of the Electromyogram

Kevin McGill, Ph.D., and Leslie Dorfman, Ph.D.
Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The electromyographic (EMG) examination plays an important role in the diagnostic evaluation of many neuromuscular disorders. It involves recording an electrical signal from a contracting muscle using a needle electrode. In current practice, most neurologists assess EMG signals in a way that is qualitative and subjective—by listening to their sound and by watching their pattern as they flash across an oscilloscope screen in real time.

There is a widely felt need for a quantitative method for analyzing EMG signals that would be more objective, more reproducible, and more diagnostically sensitive than the subjective methods in current use.

Two major approaches to quantitative EMG analysis have been taken. The first has been to decompose the signal into its compo-

nent motor-unit action potentials (MUAPs). This has proved diagnostically sensitive but is limited to weak contractions because of the difficulty of decomposing high-force EMG signals, commonly called “interference patterns” because of their resemblance to random noise. The second approach has been to try to characterize high-force interference patterns statistically—for example, by their power spectral density. This has proved insensitive and unreliable. Thus, no method of quantitative EMG analysis has gained wide acceptance.

Progress—We hypothesized that advanced signal-processing techniques could be employed to efficiently and accurately decompose moderately complex EMG interference patterns into their component MUAPs.

We wrote a computer program (ADEMG—Automatic Decomposition Electromyography) for extracting MUAPs from EMG signals recorded during conventional EMG examinations. The program achieves greater speed and accuracy than existing EMG analysis methods through the use of four innovative signal-processing techniques: 1) a fast digital filter for transforming MUAPs into sharp spikes that can be easily detected and accurately identified; 2) an efficient algorithm for aligning and comparing spikes that achieves high temporal resolution at a low sampling rate; 3) a method for verifying or rejecting tentatively identified MUAP trains based on the regularity of their interspike intervals; and 4) a new noise-reducing algorithm for back-averaging the MUAP waveforms from the raw signal using their identified spikes as triggers. The program can

analyze a 10-second EMG signal in 90 seconds of computation time and is able to decompose signals containing as many as 15 MUAP trains.

Preliminary Results—We used ADEMG as implemented on a PDP-11/34 minicomputer to collect normative MUAP properties for the biceps muscle and are continuing to collect a database of properties from other muscles and from patients with known neuromuscular disorders. Tests of the ADEMG method's accuracy and diagnostic sensitivity involving computer simulations and a comparative study with other quantitative EMG techniques on groups of patients with selected neuromuscular disorders are under way. ADEMG is also being implemented on a commercial electromyograph to make it more widely available to neuromuscular electrodiagnosticians.

Quantitative Analysis of the Surface Electromyogram

Leslie Dorfman, M.D.; Kevin McGill, Ph.D.; Jane Howard, M.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Diagnostic electromyography (EMG) is an important tool in the evaluation of patients with known or suspected neuromuscular injuries or diseases. Most clinical applications of diagnostic EMG require that data be collected using intramuscular needle electrodes, which is usually a painful procedure.

If the EMG activity from superficial muscles can be quantitatively analyzed in a diagnostically meaningful way using surface (skin) electrodes, the discomfort of the procedure will be reduced. Serial EMG monitorings (e.g., of response to therapy for neuromuscular disability) would become more feasible, particularly for individuals with low pain tolerance as well as for children.

Previous studies of surface EMG have demonstrated that it does contain some diagnostically relevant information, but clinical application has been limited by distortion of the myoelectric signal from volume conduction through the interposed tissues.

Progress—We hypothesized that the surface EMG could be decomposed into its constituent motor-unit action potentials (MUAPs) using new, computer-based analysis techniques and that these surface MUAPs could be shown to contain information relevant to neuromuscular diagnosis and evaluation.

We developed a new computer technique, Automatic Decomposition EMG (ADEMG), which decomposes the EMG signal into its elemental MUAPs. This method is currently undergoing validation and clinical testing on conventional, needle-recorded EMG data. We are applying ADEMG also to the analysis of surface EMG data derived from normal individuals as well as from patients with selected neuromuscular disorders.

Preliminary Results—The Rehabilitation Research and Development's laboratory of neuromuscular electrophysiology has been equipped and configured for the collection and processing of human EMG data. This laboratory will func-

tion in parallel with the Stanford EMG lab for ADEMG processing of depth and surface EMG

recordings to continue our work in quantitative analysis.

A Smart Trigger for Real-Time Neuroelectric Spike Classification

Kevin McGill, Ph.D., and Leslie Dorfman, M.D.

Veterans Administration Medical Center, Palo Alto CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Neuroelectric signals recorded from muscle, nerve, and brain often contain action potentials or “spikes” arising from more than one cell. In order to examine the behavior of the individual cells, it is necessary to sort out the spikes. Some applications demand that this sorting be done with high accuracy in real time.

Important applications for a high-performance real-time spike classifier include basic electrophysiology, single-fiber electromyography (SFEMG), and functional electrical stimulation (FES). In basic electrophysiology, such a device would make studies of cellular behavior easier and more accurate. In SFEMG—a technique for diagnosing neuromuscular disorders in which a sensitive needle electrode is used to observe the discharges of individual muscle fibers—such a device would make the SFEMG examination less technically difficult and more practical for widespread use. In FES, such a device could be used to derive control signals for a prosthesis or paralyzed muscle from the discharges of individual motor units in an intact muscle. Presumably, these control signals would reflect the user’s intentions more sensitively than signals derived from gross surface EMG.

At present, spikes can be sorted in real time by an electronic device called a window discriminator, or they can be sorted off-line by computer. Window discriminators are fairly simple, and hence somewhat intractable and simple-minded; they require careful hand tuning, have difficulty distinguishing similarly shaped spikes, are sensitive to changes in spike shape, and give unsatisfactory results if more than two or three spike trains are present. Computer analysis, on the other hand, can achieve excellent sorting performance by bringing sophisticated signal-processing algorithms

to bear. Up to now, however, computer analysis has been too slow for real-time use.

Progress—We hypothesized that powerful signal-processing algorithms for spike detection and discrimination could be implemented on today’s fast microprocessors to build an inexpensive high-performance real-time trigger. We expected that this device would be a useful instrument in basic electrophysiology and that it would simplify SFEMG examinations, thus making SFEMG diagnosis more common and more reliable.

We designed a device, which we call the Smart Trigger, that is able to automatically discriminate up to eight different spike waveforms on a single input channel and can deliver trigger pulses on eight separate output lines. It can be set to trigger on the input signal itself or on its first or second derivative. (Differentiation often improves triggering performance by flattening the signal baseline and sharpening the spikes.) The Smart Trigger uses the template-matching method—which takes into account the spike’s full waveform rather than just a few features—to sort the spikes. The waveform of each spike that crosses a detection threshold is characterized by a 16-word “signature,” and a template is stored for each different signature encountered. When the same signature is detected four times, it is assigned to an output line, and thereafter a trigger pulse is generated on the line each time a spike with that signature is detected. The templates are constantly updated to track slow changes in spike shape.

Preliminary Results—A prototype of the Smart Trigger is nearing completion. It employs three microprocessors operating in parallel. The input signal is sampled by an analog-to-digital

converter at a rate of from 1 to 20 kHz. The samples are fed into a TMS-320, which maintains templates of the previously encountered spikes. It compares the incoming spike with each template, decides if it matches one of them, updates or forms a new template as appropriate, and assigns recurring spikes to output lines. The system is controlled by an

M68000 microprocessor that also manages the front-panel switches and displays. To compensate for the delay through the system, the M68000 also buffers the input signal (on an auxiliary channel) to provide, via a digital-to-analog converter, a delayed version synchronized with the trigger pulses.

The EMG-Force Relationships of Skeletal Muscles Depends on Their Firing Rate and Recruitment Control Strategies

M. Solomonow, Ph.D.; R. Baratta, M.Sc.; B. H. Zhou, E.E.; H. Shoji, M.D.; R. D'Ambrosia, M.D.

Bioengineering Laboratory, Department of Orthopaedic Surgery, Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: *LSU Bioengineering Foundation*

Purpose—The linearity/nonlinearity of the EMG-force relationships of various skeletal muscles has been a topic of much interest and controversy. Important clinical applications of such basic knowledge await in gait, kinesiology evaluation, neurological diagnosis, and utilization of EMG in FES systems as a force feedback.

Progress—An adaptive stimulation system was designed and used in animal studies. The system can induce simultaneous control of firing rate and recruitment of motor units according to their size. Capabilities also allow recruitment of all the motor units to be completed when the firing rate is still increasing at

various proportions.

Preliminary Results—Findings show that the EMG-force relationships are linear if recruitment is accounted to generate the initial 50 percent of the maximal force and firing rate the final 50 percent. As the recruitment range increases above 60 percent, the relationships become progressively nonlinear. The major conclusion on the results obtained so far from the m. gastrocnemius muscle clearly indicates dependence of the EMG-force relationship on the muscle control strategy.

Current studies explore the response of the soleus—a slow-twitch muscle to similar control strategies.

C. Muscle Fatigue

Muscle Fatigue and the Myoelectric Signal

Carlo J. De Luca, Ph.D

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Purpose—The use of the myoelectric signal to objectively measure the rate at which a muscle fatigues has numerous rewarding prospects. The approach is based on the proven fact that the frequency spectrum of the myoelectric

signal detected with surface electrodes changes in a systematic fashion during sustained contractions. High-frequency components decrease in amplitude, whereas low-frequency components increase.

Various studies during the past two decades have searched for the cause of this frequency shift and have specifically attempted to determine whether the change originates from the physical properties of muscle fibers such as their conduction velocity, or originates from control properties such as firing statistics. Although the origin of the change is not clearly understood, the effect on the frequency spectrum is consistent and is related to the progression of a sustained muscle contraction. For this reason it provides a useful mechanism for assessing the involvement of the physiological component in the fatigue characteristics displayed by individuals performing a task.

The objective measurement of physiological fatigue is essential to offset the seriously erro-

neous subjective evaluations that occur when psychological components are not isolated. Consequently, it is a vital tool in both industrial and health-care environments where the evaluation of fatigue-producing tasks is important.

Progress—To achieve these goals we have developed a device called the Muscle Fatigue Monitor (MFM), which automatically, on-line and in real-time, calculates and plots a single-parameter measure of the frequency shift.

A review article documenting the known facts describing the possible cause of the frequency shift, as well as evolving applications of the technique, was published in *CRC Critical Reviews in Bioengineering*. Another article was published in the *Journal of Applied Physiology*.

Muscle Fatigue and Back Pain

Viktor R. Tiegermann, Ph.D.; Serge H. Roy, M.S.P.T.; L. Donald Gilmore, A.B.E.E.; Carlo J. De Luca, Ph.D.
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: VA Rehabilitation Research and Development Service

Purpose—As many as 75 million Americans now suffer from severe lower back pain, and each year 7 million more people develop this problem. Despite the many millions of dollars spent on innumerable treatments for the back, the majority of patients have chronic, remitting symptoms. Improved methods for assessing back disorders could help to diminish the problem and the financial burden of this disabling condition.

Progress—We have begun to develop and implement a technique to provide the clinician with an objective index with which to measure treatment-outcome for lower back musculature. This technique estimates the fatigue rate of contracting muscles by measuring the shift occurring in the frequency spectrum of the surface-detected myoelectric signal. The dynamic interaction of synergistic back muscles during fatiguing contractions can be represented by "fatigue patterns" created by the different fre-

quency shifts occurring in different muscles. Differences in these patterns associated with lower back disorders may represent functional disturbances in back muscles.

In preparation for implementing this technique, we have designed and constructed a restraining device to reliably stabilize the trunk in selective positions from sitting to standing. The device is equipped with strain-gauge load cells to monitor flexion, extension, or rotation torques of the trunk. A force meter placed in front of the subject provides visual feedback. In addition, preliminary modifications of another device will permit the analysis of multiple channels of myoelectric signals and will track the median frequency of the signal.

Data from 6 patients with chronic lower back pain and 16 normal controls are presently being analyzed. Preliminary results indicate substantial differences in the fatigue curves for these two groups. Additional tests to augment the sample size are under way.

Fatigue Properties of Motor Units During Voluntary and Electrically Induced Contractions

Roberto Merletti, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company; Politecnico di Torino, Torino, Italy*

Purpose—A major difficulty in the clinical application of functional electrical stimulation techniques is the high rate of fatigue observed in stimulated contractions. This problem is of concern when attempting to ambulate paraplegic patients or to define optimal patterns of electrical stimulation for scoliosis correction. A research project to investigate the problem was undertaken. We hope to develop optimized strategies for electrical stimulation that will improve clinical applications in rehabilitation.

During voluntary contractions, motor units fire at different rates. Each firing rate is affected by a number of deterministic and stochastic factors. The resulting signal is known as the interference myoelectric pattern. In comparison, electrically stimulated contractions result in synchronously firing motor units. Each stimulation pulse generates a sequence of responses called M-waves. This technique removes most of the stochastic components from the myoelectric signal. It is therefore possible to identify the effect of the firing-rate statistics on the surface myoelectric signal.

The recruitment order of motor units is different for voluntary versus electrically elicited contractions. Fatigue-resistant motor units are recruited first during voluntary contractions and last during electrically induced contractions. Comparisons of these contractions for low force levels is expected to provide information about the properties of the motor units belonging to the extremes of the fiber type spectrum.

Progress—Mean and median frequency as well as conduction velocity of the M-wave were measured in the tibialis anterior muscle. Results were compared to those obtained during voluntary contractions. Preliminary results showed that the median or mean frequency was not directly proportional to the muscle-fiber conduction velocity. Furthermore, firing-rate statistics may not explain this lack of direct proportionality.

An article describing the technique used in this project was published in *IEEE Transactions on Biomedical Engineering*.

Muscle Fatigue Monitor

L. Donald Gilmore, A.B.E.E.; Henry Sprenkels; Humphrey DeWinter

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Progress—The Muscle Fatigue Monitor (MFM) is an instrument that allows us to objectively measure muscle fatigue in subjects in both laboratory and field environments. The device has evolved through a series of stages, culminating in the present form. It calculates the median frequency of the myoelectric signal that occurs during a sustained contraction, using electrodes placed on the skin above the subject's muscle. Changes in the median frequency during a sustained muscle contraction are associated with the muscle fatigue process. A detailed descrip-

tion appears in our paper, "Muscle Fatigue Monitor (MFM): Second Generation," published in *IEEE Transactions on Biomedical Engineering*, January 1985. The portable MFM device has proved useful for studying the underlying processes of muscle fatigue. We believe that such a powerful tool should be accessible to other laboratories and organizations collaborating with our muscle-fatigue research projects.

In an effort to make the MFM concept available to other researchers, we are now developing a more generalized MFM instrument

based on the IBM PC computer. Although not as portable as the present generation MFM, the PC-based system will offer the advantage of more powerful color graphics, data manipulation, and commercial software well suited to the laboratory environment. The electronic circuitry used to measure muscle fatigue will be designed to be compatible with the standard card slots of the IBM PC series computers. Because many laboratories already possess an IBM PC-based system, the MFM circuit boards

and floppy-disk MFM software are the only items necessary to complete a powerful fatigue measurement workstation.

A prototype version of this PC-based MFM system has been developed in our laboratory and was demonstrated at the International Rehabilitation Exhibition in New York in April 1986. An article describing the second generation MFM was published in *IEEE Transactions on Biomedical Engineering*.

IX. Ligaments and Tendons

Muscle Fatigue and Back Pain

Viktor R. Tiegermann, Ph.D.; Serge H. Roy, M.S.P.T.; L. Donald Gilmore, A.B.E.E.; Carlo J. De Luca, Ph.D.
NeuroMuscular Research Center, Boston, MA 02215

Sponsor: VA Rehabilitation Research and Development Service

Purpose—As many as 75 million Americans now suffer from severe lower back pain, and each year 7 million more develop this problem. Despite the many millions of dollars spent on innumerable treatments for the back, the majority of patients have chronic, remitting symptoms. Improved methods for assessing back disorders could help to diminish the problem and the financial burden of this disabling condition.

Progress—We have begun to develop and implement a technique to provide the clinician with an objective index with which to measure treatment outcome for lower back musculature. This technique estimates the fatigue rate of contracting muscles by measuring the shift occurring in the frequency spectrum of the surface-detected myoelectric signal. The dynamic interaction of synergetic back muscles during fatiguing contractions can be represented by "fatigue patterns" created by the different frequency shifts occurring in different muscles.

Differences in these patterns associated with lower back disorders may represent functional disturbances in back muscles.

Preliminary Results—In preparation for implementing this technique, we designed and constructed a restraining device to reliably stabilize the trunk in selective positions from sitting to standing. The device is equipped with strain-gauge load cells to monitor flexion, extension, or rotation torques of the trunk. A force meter placed in front of the subject provides visual feedback. In addition, preliminary modifications of another device will permit the analysis of multiple channels of myoelectric signals and track the median frequency of the signal.

Data from 6 patients with chronic lower back pain and 16 normal controls are currently being analyzed. Preliminary results indicate substantial differences in the fatigue curves for these two groups. Additional tests to augment the sample size are underway.

Structural and Functional Properties of Normal and Repaired Ligaments

Savio L-Y. Woo; Richard Gelberman, M.D.; David Amiel, Dip.Ing.; Steven Garfin, M.D.; Wayne Akeson, M.D.
Veterans Administration Medical Center, San Diego, CA 92161

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of this research is to evaluate the ligament repair process in a model synovial joint system. A variety of activity conditions will be used in order to determine which set of conditions will maximize the speed and strength of the repair or healing of ligaments. To achieve this objective, it will be necessary to determine the influence of a wide range of physical factors such as rigid immobilization, cage activity, normal activity, intermit-

tent controlled passive motion, and rigorous daily exercise programs on the size and strength of normal and repaired/healing ligaments. The timing of the onset of these forces at the repair line and its magnitude and frequency would need to be optimized in order to achieve the most rapid and complete remodeling of the repaired/healing ligament.

Progress—To date, we have studied medial col-

lateral ligament healing with and without surgical repair using a canine model. The evaluation of the quality of ligament healing and repair has included correlative studies using morphologic, biomechanical, and biochemical techniques. Specifically, we have studied healing ligaments subjected to various regimens of repair and early mobilization over a 6-week time period. We have focused on the biomechanical properties of the ligament repair site and the areas of the ligament proximal and distal to the repair. The structural and mechanical properties obtained were in turn com-

pared to the biochemical results and histological appearance of each of these areas, and very good correlations were found. We are currently performing experiments over a 12-week period to further define proper clinical regimens that may be used to provide better healing of ligament structures. Our goal is essentially twofold: first, to improve the structural integrity of the healing ligament to ameliorate problems of knee joint instability and second, to improve the material properties of the healing ligament substance.

Tensile Properties of the Medial Collateral Ligament as a Function of Age

Savio L-Y. Woo; Carlo A. Orlando; Mark A. Gomez; Cyril B. Frank; Wayne H. Akeson

Division of Orthopaedics and Rehabilitation, University of California, San Diego; and San Diego Veterans Administration Medical Center, La Jolla, CA 92103

Sponsor: VA Rehabilitation Research and Development Service

Progress—The biomechanical properties of the rabbit medial collateral ligament (MCL) as a function of maturation and age were investigated. Femur-MCL-tibia (F-M-T) preparations were obtained from rabbits of different age groups (open or closed epiphysis). Parallel increases in the animal body weight and ligament cross-sectional area were recorded with age. Cyclic and tensile failure tests were performed to obtain the structural properties of the F-M-T complex and the mechanical properties of the MCL substance. There were significant increases in the load at failure, energy-absorbing capability of

the bone-ligament junction, and in the tensile strength of the ligament substance as a result of maturation and subsequent aging. Increases in the area of hysteresis obtained during cyclic loading-unloading were also documented. At the closing of the epiphysis, the mode of failure of the F-M-T structure progressed from tibial avulsion to failure in the midsubstance of the ligament. An asynchronous rate of maturation was observed between the structural properties of the bone-ligament complex and the mechanical properties of the ligament substance.

Effects of Postmortem Storage by Freezing on Ligament Tensile Behavior

Savio L-Y. Woo; Carlo A. Orlando; Jonathan F. Camp; Wayne H. Akeson

Division of Orthopaedics and Rehabilitation, University of California, San Diego; and San Diego Veterans Administration Medical Center, La Jolla, CA 92103

Sponsor: VA Rehabilitation Research and Development Service

Progress—The purpose of this study was to examine the effect of prolonged postmortem freezing storage (between 1 and 3 months at -20 degrees C) on the structural properties of the medial collateral ligament (MCL)-bone complex as well as the mechanical properties of the MCL substance from the rabbit knee. Tensile testing of the femur-MCL-tibia specimen was

performed, and no statistically significant changes were noted between the fresh and stored samples in terms of the cyclic stress relaxation; the load-deformation characteristics; as well as the load, deformation, and energy absorbing capability at failure. The area of hysteresis of the stored samples was significantly reduced in the first few cycles, however. The

mechanical properties of the MCL substance, as represented by the stress-strain curves, tensile strength, and ultimate strain also did not change following storage. We concluded, there-

fore, that proper and careful storage by freezing has little or no effect on the biomechanical properties of the ligaments.

Structural and Mechanical Behaviors of Tendons and Ligaments ---

Savio L-Y. Woo and Wayne H. Akeson

University of California, San Diego and San Diego Veterans Administration Medical Center, La Jolla, CA 92103

Sponsor: VA Rehabilitation Research and Development Service

Progress—This research demonstrated the use of improved technology and experimental methodology to gain more accurate data on the mechanical and structural properties of soft tissues. It is possible to modify the mechanical properties of soft tissues by altering the contents and interactions of its constituents *in vivo* by increasing or decreasing the levels of stresses and motion.

The data and techniques available today can be used to evaluate the success or failure in the treatment of soft tissue injuries. It has been clearly demonstrated that early mobilization is

desirable for management of soft tissue trauma. As a result, the therapeutic values of continuous passive motion or intermittent passive motion have received significant clinical attention. However, complications such as failure of the repair mechanism as well as stretching out of soft tissues, particularly in the case of ligaments, can cause joint laxity if motion is applied too early and too aggressively. Therefore, it is necessary to narrow the range of the spectrum of motion versus immobilization in the management of soft tissue trauma.

X. Arthritis

The Use of Biofeedback and Cognitive Behavioral Psychotherapy in the Treatment of Severe Rheumatoid Arthritis Patients: A Controlled Evaluation

Kenneth E. Applebaum; Edward B. Blanchard, Ph.D.; Maria Paz-Alfonso, M.D.; Edward J. Hickling, Psy.D.
East Orange Veterans Administration Medical Center, State University of New York, Albany, NY and Veterans Administration Medical Center, Albany, NY 12208

Sponsor: VA Medical Center and State University of New York at Albany

Purpose—According to the Arthritis Foundation, arthritis is the number one crippling disease in the United States. The majority of all arthritis patients under the age of 45 are those with rheumatoid arthritis (RA). Five million individuals in the United States have RA. Little is known about the etiology of this disease; however, it is known that RA may manifest as a chronic and degenerative disease. This deterioration may affect many aspects of life, including psychological and functional activities.

Medical treatment provided by a multidisciplinary team has become the standard to treat the RA patient. Within this team approach, psychophysiological intervention, as an adjunct to the standard medical regimen, has been used. Psychophysiological treatments have included relaxation training, biofeedback, and cognitive behavioral approaches to chronic pain. These interventions have a logical basis with regard to the maintenance of the RA condition. Lysosomal activity in the inflamed joints may prove differentially responsive to thermal biofeedback. Also, the behavioral manifestations accompanying chronic pain may be amenable to cognitive behavioral interventions in an effort to help patients cope and deal with the chronic nature of the RA condition.

Progress—This study utilized both a within-groups and a between-groups design in an effort to assess the effectiveness of a psychophysiological approach to the treatment of RA. An active treatment group was compared with a wait list control group. Both groups received pre- and post-assessments. The treatment consisted of progressive relaxation training, ther-

mal biofeedback, and cognitive-behavioral approaches to the treatment of chronic pain. Both groups were monitored for pain, sleep, and medication indices for a 10-week period, using both psychological and functional test measures during the treatment.

The participants in this study were 18 Stage II and Stage III RA sufferers, 8 males and 1 female per group. All subjects were from the Albany Veterans Administration Medical Center, referred from the Rehabilitative Medicine or Rheumatology Services.

During the initial assessment, a detailed arthritis history was administered to each subject. Additionally, psychological measures including the Beck Depression Inventory, State Trait Anxiety Inventory, McGill Pain Questionnaire, MMPI, and Functional Activities Questionnaire were administered. Following the completion of these inventories, all patients were shown how to monitor pain, sleep, and medication indices on preprinted arthritis diaries. At the conclusion of this initial assessment, all patients were assessed in Physical Therapy for range of motion, grip strength, and timed walk.

At the conclusion of the initial assessment, all patients in the wait list control group were instructed to monitor pain, sleep, and medication indices for a 10-week period of time. The patients in the active treatment group were asked to return to the hospital in 2 weeks in order to begin treatment. Treatment consisted of twice-weekly meetings for the first 4 weeks. Then, once-a-week meetings were held for 2 weeks. Two weeks after the last treatment session, patients in the active treatment group re-

turned to the hospital for post-treatment assessment. Thus, all patients in each group had a pre-assessment followed in 10 weeks by a post-assessment.

Preliminary Results—All data have been collected and are currently undergoing analysis. It is hoped that this intervention will have afford-

ed an improvement in chronic pain and adjustments that these patients have in their daily living. It is conjectured that this may be due to the perceived sense of control gained in psychophysiological intervention as well as modest improvements in physical functioning. Depending on results of this study, a more comprehensive ambitious project may be begun.

Arthritis Rehabilitation Unit

Carolyn Brunner, M.D.; Cynthia Stabenow, OTR; Stephen Wegener, Ph.D.; Amy O'Leary, MA
Rehabilitation Research and Training Center, University of Virginia Medical Center, Charlottesville, VA 22908
Sponsor: National Institute of Handicapped Research

Purpose—The purpose of the Arthritis Rehabilitation Unit (ARU), which consists of five beds in a 22-bed general rehabilitation unit, is to identify methods of managing arthritis patients that will result in either keeping them employed or in eliminating the need. The staff consists of a rheumatologist, orthopedic surgeon, psychiatrist, rehabilitation nurses, occupational and physical therapists, social workers, psychologists, and a vocational rehabilitation counselor.

Progress—To date, more than 160 patients have been admitted to the inpatient rehabilitation program. The primary diagnosis is rheumatoid arthritis, although patients with other diagnoses such as osteoarthritis and ankylosing spondylitis are admitted.

During the grant period the staff of the ARU have been collecting demographic data on patients participating in the program. In addition, the staff is using the Arthritis Impact Measurement Scale, an outcome measure developed at the Boston University Multipurpose Arthritis Center, to assess patients on nine scales: mobility, physical activity, dexterity, household activity, social activity, ADL, pain, depression, and anxiety. Three-month, 6-month, and 1-year followup data are collected on all of the patients at the rehabilitation unit to help determine the long-term benefits of the rehabilita-

tion program.

Training efforts have included a program in arthritis for the rehabilitation nurses on the unit, a physical therapy consultant to discuss management of musculoskeletal problems in arthritis for the entire staff, a statewide program for public health nurses in rehabilitation of patients with arthritis, and a nationwide video conference on management of arthritis using the multidisciplinary team approach.

The staff has completed a survey of more than 500 rehabilitation units to help determine the scope of arthritis rehabilitation in the United States and the need for staff training in management of arthritis patients. The ARU staff has also been engaged in a cooperative effort with the Virginia Division of Rehabilitation Services to place a part-time vocational counselor in the Arthritic Clinic and make available a program evaluator to interview patients. Information is gathered on their employment status or disability status to determine the extent to which people with arthritis are placed on disability and the extent to which rehabilitation services are utilized.

The staff currently has two research projects under way. These include an investigation of sleep problems in patients with rheumatoid arthritis and an outcome study of equipment use following discharge from the inpatient rehabilitation program.

Impact of Arthritis Self-Care for Rural Persons

Jean Goeppinger, Ph.D.

University of Virginia, School of Nursing, Charlottesville, VA 22903

Sponsor: *National Institute of Handicapped Research*

Purpose—The purpose of the Arthritis Self-Care (ASC) project is to develop and evaluate the impact of arthritis self-care programs for rural persons. The independent variable is type of arthritis self-care program, correspondence course, or small-group format; the dependent variables are knowledge, self-care behavior, pain, depression, and function/disability; intervening variables are self-care efficacy and social support.

Progress—Between 1982 and 1984 we: 1) conducted an assessment of the education needs of rural persons with arthritis; 2) developed the self-care curriculum; 3) "packaged" the curriculum in six classes that are offered to the participants in either the correspondence course or small-group format; and 4) completed a study of the psychometric properties and ease of administration of selected instruments to assess ar-

thritis pain and function.

Preliminary Results—In 1985 we: 1) began the process of entry into the rural communities selected as research settings; 2) identified and trained approximately 55 lay persons as community coordinators of the correspondence course or as lay leaders of the small groups; 3) recruited participants; and 4) completed the processes of random assignment, pretesting, and intervention with the first cohort of participants ($N = 250$). In 1986 we completed random assignment, pretesting, and intervention with a second cohort of participants ($N = 250$). We also began the collection of post-test data, at 4-month, 8-month, and 12-month intervals. Throughout the project we have presented our preliminary findings at professional meetings, regional and national, and have recently begun to publish our results.

Multipurpose Arthritis Center: Stanford University

Halsted R. Homan; James F. Fries; Deborah P. Lubeck; Diana B. Dutton

Stanford University, Palo Alto, CA 94304

Sponsor: *National Institutes of Health*

Purpose—The Stanford Arthritis Center (SAC) conducts research, educational, and patient care programs to improve health outcomes of arthritic patients. In particular, SAC designs and implements new educational and community programs and gauges their success by outcomes experienced by patients. To do so, SAC draws upon multifaceted research activities, large numbers of patients and community physicians, cooperating hospitals and health services, a major system for managing data (ARAMIS), and skills of economists, epidemiologists, educators, and health professionals in assessing new programs.

Progress—Central to SAC activities is develop-

ment of reliable methods to evaluate health outcomes. SAC has developed instruments measuring functional status, symptoms, adverse effects of drugs, and costs of health care for arthritic persons; other instruments, particularly concerning psychological variables and quality of life, are in developmental phases. This work depends upon a core unit that assists in experimental design, instrument development, data management and computational issues, biostatistics, and data analysis.

Continuing are seven successful programs concerning long-term outcomes for rheumatoid arthritis, juvenile arthritis and joint replacement; self-management education for patients; comparison of osteoarthritis outcomes in three

different health services; comparison of team versus individual physician care of chronic arthritis of the elderly; and treatment of refractory lupus nephritis with total lymphoid irradiation. Six new projects are added, all related to chronic arthritis: identification of influential psychological factors; analysis of incidence by population characteristics; a new method for estimating indirect costs; the impact of exercise on incidence of osteoarthritis; distinction be-

tween seronegative and seropositive arthropathies; and search for a pathogenic antigen in cartilage of rheumatoid joints.

Improved outcomes for arthritic patients nationally must occur within the limits of financial resources available. This center develops and evaluates care programs for large groups of arthritic patients with the objective of improving the effectiveness, efficiency, and satisfaction achieved by health services.

Multipurpose Arthritis Center: Boston University

Robert F. Meenan

Boston University, School of Medicine, Boston, MA 02118

Sponsor: National Institutes of Health

Purpose—This proposal describes in detail a plan to expand and strengthen the Boston University Multipurpose Arthritis Center (MAC). A program of activities and specific projects will be pursued in three major components: research, education, and community/health services research. The proposal also describes a plan to support areas of special research interest by means of two core units and to continue an effective administration component.

The research component will build on a strong base of work funded from other sources. In addition, four developmental and feasibility studies are proposed: 1) a study of Vitamin A metabolism in prealbumin forms of amyloid disease; 2) the isolation of cDNA clones for serum amyloid A; 3) an investigation of stair climbing and arthritis; and 4) a study of the difficulty dimension in functional assessments.

Progress—MAC education efforts will continue to be aimed at a broad spectrum of arthritis health professionals in conjunction with the Schools of Medicine, Nursing and Allied Health Professions of Boston University. Specific projects in the education component will include an evaluation of the current status of house officer education in rheumatology at internal medicine and family practice residency programs, a study of the effects of a targeted training program on interpersonal skills of

physical therapy students, and an investigation of coping in chronic arthritis.

Future Plans—Activities in the Community/HSR component of the MAC will continue to focus on the inner-city community in conjunction with the Department of Health and Hospitals of the city of Boston. Seven specific community/health services research projects are proposed: 1) a project to modify the Arthritis Impact Measurement Scales for use in clinical practice; 2) a project to develop a computer-based community network for clinical rheumatology trials; 3) an inner-city nursing home project combining outreach and data collection for this important population; 4) a study of the rheumatology referral behavior of general internists and family practitioners; 5) an epidemiologic study of osteoarthritis in conjunction with the Framingham Heart Study; 6) an epidemiologic study of oral contraceptives and rheumatoid arthritis in conjunction with an established drug epidemiology group; and 7) an investigation of the relationship between stressful life events and disease activity in rheumatoid arthritis.

Two core units are proposed: an amyloid studies core unit and a research and evaluation support core unit. These core units will support numerous investigations in areas of special interest to the Center.

Northeast Ohio Arthritis Center Support: Legal Aspects of Chronic Illness—A Study of Arthritis Patients

Judith P. Lipton

Case Western Reserve University, Cleveland, OH 44106

Sponsor: *National Institutes of Health*

Purpose—The long-term objectives of this proposal are: 1) to expand efforts directed towards the education of health professionals, patients, families, and the general public; 2) to develop, implement, and evaluate prototype community/health services programs at a high level of scientific endeavor; and 3) to expand clinical and basic research efforts.

Progress—New programs in education include: 1) an evaluation of use of the education-influential in teaching rheumatology to family practice training units; 2) studies of continuing graduate medical education in arthritis with emphasis upon involvement of the learner in the identification of objectives; and 3) augmentation of an audiovisual library as an umbrella educational resource.

Specific new community programs include: 1) a systems analysis of arthritis health care delivery in Northeast Ohio; 2) identification of the legal needs of arthritis (chronically ill) patients;

3) studies of the perceived needs of arthritis patients, and available resources to meet those needs as viewed by the patient and community health nurses; 4) the establishment of an industrial database pertaining to arthritis problems and management in Northeast Ohio; and 5) an evaluation of Northeast Ohio MAC/community organizations' behavioral interrelationships. Research programs are targeted to study cartilage metabolism and osteoarthritis, mediators of inflammation, acute phase reactants, the immune response in arthritis, genetic/clinical interplays in ankylosing spondylitis, and myopathic disorders.

Core programs include a cell/tissue culture unit, and an evaluation/education core as an overall resource to center project components. Administration includes administrative policy, executive, steering (operations), and community advisory committees to fully integrate center/university/community activities.

Multipurpose Arthritis Center: Community Component—Coping Responses to Rheumatoid Arthritis; Social Security Disability Study; Role Performance Limitations in Women With RA

Glenn G. Affleck; Arthur Weinstein; Susan T. Reisine

University of Connecticut Health Center, Farmington, CT 06032

Sponsor: *National Institutes of Health*

Progress—The NIH Multipurpose Arthritis Center is currently funding four major educational efforts: the computer-assisted patient education project, the physician-assisted program, family resident training education, and physical therapist education.

The computer-assisted patient education project has successfully completed a program for patients and families of patients with rheumatoid arthritis. This has been well received by patients and is currently undergoing testing by both patients and their families. Editing of the

program will proceed along with the evaluation process.

The physician-assisted program has completed a longitudinal study in which physicians are in contact with a patient with rheumatoid arthritis (the computer) over a period of 7 years. This is being evaluated by various types of physicians and by medical students. Editing of the program will continue as the evaluation proceeds.

The third program involves developing methods for teaching family medicine residents

and is continuing during the next year in which more data will be available and the testing methods improved.

The fourth program involves teaching methods and content development in the area of physical therapy. Undergraduate teaching of rheumatology by our NIH Multipurpose Arthritis Center funded physical therapist-educator is now in progress, and efficacy will be evaluated

during the coming year.

The research project on C3 phenotypes has led to interesting findings in that juvenile onset systemic lupus erythematosus patients have a higher incidence of one phenotype than adult onset patients. Patients with other rheumatic diseases are currently being evaluated. The Administrative Unit is functioning adequately for the Center.

Multipurpose Arthritis Center: Pain Management in Arthritis; Physical Conditioning Exercise Programs for the Arthritis Patient; Motor Skill Learning; Mini-Sabbatical for Physical and Occupational Therapists

Jerry C. Parker; Marian A. Minor; Terry D. Tenbrink; Marilyn K. Sanford

University of Missouri, Department of Medicine, Columbia, MO 65212

Sponsor: *National Institutes of Health*

Purpose—We propose the following objectives under education and training: 1) train arthritis specialist professionals to become educators; 2) provide high quality continuing education programs for all professionals; 3) develop improved curricula in musculoskeletal disease for undergraduate and graduate education of primary care professionals; and 4) study the effect of patient education and team care in knowledge, attitudes, and behavior in rheumatoid arthritis.

The research objective of our work is to determine if a computer-assisted program can increase the efficacy of the expert rheumatologist to influence favorably the medical management

for arthritis patients.

The community program objective is to: 1) determine the needs of various communities as related to arthritis; 2) plan programs best suited to meet these needs; and 3) conduct community demonstration programs in public and professional groups.

Methods will include questionnaires on information, attitudes, and behavior; computer analysis, regional and national conferences; team visits to communities; and personal participation in a multidisciplinary team approach to patient care in arthritis.

Multipurpose Arthritis Center: Community Component—Studies Using a Panel of Rheumatoid Arthritis Patients; Secondary Data Studies; Education Component—Arthritis In-Service Program for Home Health Agencies

Edward H. Yelin and Ida M. Martinson

San Francisco General Hospital, San Francisco, CA 94110

Sponsor: *National Institutes of Health*

Purpose—The Multipurpose Arthritis Center conducts a broad range of activities in each of three areas—education, community programs, and research. A strong basic research program includes studies in the underlying mechanisms of the rheumatic diseases, particularly immunological mechanisms. Almost all this research is supported by sources other than the center

grant. Among the activities directly supported by the current grant, the highest priority is given to education, particularly education of primary care physicians, nurses, and allied health professionals.

One objective is to improve the knowledge and skills of students and practitioners of these disciplines in caring for people with arthritis.

High priority is also given to research on a variety of issues in the delivery of health care to people with arthritis. Other objectives of this research are to construct a database in such areas as the distribution of rheumatology manpower, the costs and utilization of health services, and the causes and consequences of work

disability, and to analyze the data for their implications for public policy.

The center also conducts programs in patient and public education and is both an advocate in the community for people with arthritis and a source of authoritative information about the special needs of this group.

A National Arthritis Data Source (ARAMIS)

James F. Fries

Stanford University, Palo Alto, CA 94304

Sponsor: *National Institutes of Health*

Purpose—ARAMIS (the American Rheumatism Association Medical Information System) is a rheumatic disease computer data bank system containing longitudinal clinical data for approximately 19,000 patients and 120,000 patient encounters, and representing more than 100,000 patient-years of observation. The system operates from an IBM 370/3081 computer at Stanford University and is accessed nationally through TYMNET or TELENET communications networks using the Time-Oriented Data Bank (TOD) data management system.

Progress—The program is based upon the premises that chronic diseases have become the most prevalent health problems, that study of such diseases requires observation of occurrences over prolonged time periods, that the expense of longitudinal study requires use of economies of scale, that patient outcome in chronic disease results from a complex interplay between multiple factors, and that many important questions need to be studied with observation and experiments. This program has the goal of improving knowledge, management, and patient outcome in arthritis by providing long-term information relating disease severity, patient characteristics, social factors, and treatment to patient outcome.

The program has two major aims: first, to continue to develop a national data resource of high quality, longitudinal, accessible clinical data; and second, to employ these data in a systematic, multicenter investigative program of major clinical questions in the rheumatic diseases. Program priorities include the classification and definition of diseases, the systematic study of long-term (6- to 20-year) outcomes, the economic impact of illness and treatment, and study of regional and national differences. Thirty clinical investigators and epidemiologists at 12 institutions undertake more than 50 projects annually.

The present proposal includes classification studies of osteoarthritis, rheumatoid arthritis, vasculitis, and systemic lupus erythematosus; economic impact studies in each major disease; comparative studies of arthritis at different sites; population-based studies of incidence and prevalence; and long-term studies of outcome in rheumatoid arthritis, juvenile arthritis, scleroderma, systemic lupus, osteoarthritis, and following joint surgery. With this project, 15 years of data development at numerous institutions are brought to bear upon major clinical questions, and very large and detailed longitudinal patient data sets are made nationally available.

Epidemiology Program Project: Rheumatoid Arthritis—Course and Outcome

Leonard T. Kurland

Mayo Foundation, Rochester, MN 55901

Sponsor: *National Institutes of Health*

Purpose—Under the Rochester Epidemiologic Program Project (REPP), a unique population-based data source, covering the medical histories of the Olmsted County population throughout their local residence, has been developed.

Progress—This central diagnostic index has served as the basis for over 180 epidemiologic studies on a myriad of topics—many relating to critical health issues of national importance, and all with excellent case ascertainment. The research facility has been used not only by the REPP staff, but also by many clinical and public health colleagues both within and outside of the Mayo Clinic. The REPP provides the population-based data for several other major program projects, including the Comprehensive (Minnesota) Epilepsy Center and the Mayo Stroke Center. The continued updating of the central diagnostic index is essential to preserve this research potential.

Future Plans—In the near future it will be necessary to obtain support for our epidemiologic program from the several categorical institutes of NIH. The purpose of this continuation proposal is to apply for funds that will allow for an orderly transition without a breakdown of the basic system. In this proposal, we request funding for: 1) continued supplementation of the Mayo Clinic diagnostic index with data from the Olmsted Medical group, Olmsted Community Hospital, and several other non-Mayo sources of medical care in Olmsted County; 2) the development, from the medical records, of an Olmsted County population frame to permit unbiased selection of controls for case-control studies; 3) development of methods within the database for studies of familial aggregation; 4) continued support for epidemiologic projects now nearing completion, such as rheumatic fever, prostate cancer, and cholelithiasis; and 5) new studies in limb fractures and trauma to the nervous system.

Multipurpose Arthritis Center: Problem-Oriented Educational Program for Arthritis Using Aerobic-Type Exercise

Susan G. Perlman

Northwestern University, Chicago, IL 60611

Sponsor: *National Institutes of Health*

Purpose—This MAC proposal engages scholars and scientists from various schools and departments of Northwestern University and from the community in a comprehensive arthritis program. Five feasibility projects are proposed: cell cytotoxicity in rheumatoid arthritis; phenytoin modulation of collagen and collagenase synthesis in synovial cells and effect on macrophages; connective tissue constituent immunogenicity in juvenile chronic arthritis; synovial pathology in early osteoarthritis; and analysis of osteoarthritic and rheumatoid bone for use in prosthesis design. These projects will support new young scientists as well as allow three

senior scientists to extend or redirect their work.

The second area of focus is an interdisciplinary educational program, utilizing a problem-solving approach, aimed at both professionals and patients. The three projects proposed are to: train and evaluate rheumatology fellows as teachers of medical residents using a new curriculum to be developed in outpatient musculoskeletal disease; evaluate a problem-oriented, aerobic-like exercise program for arthritics; and use a discussion group format to enhance problem-solving skills in the older osteoarthritic. The interdisciplinary team includes profession-

al educators, a medical education evaluator, and health professionals at the medical school.

The third area of focus, community and health services research, draws upon a strong base of community involvement combined with the research excellence of Northwestern's Center for Health Service and Policy Research (CHSPR). Three interrelated projects explore various aspects of knee pathology. The first will develop and validate a measure of outcome for a subsequent comparative study. The second will examine the costs of treatments for osteoarthritis of the knee. The third builds upon the

work of the earlier two to compare costs and efficacy of arthroscopic surgery and alternatives. Three additional projects add breadth to the research agenda focusing upon musculoskeletal impairment in the elderly, status of families with juvenile arthritic children and a multicenter study of Social Security payment allocation systems.

The Biostatistics and Data Management Core will provide individual project technical assistance as well as database management for a computerized case finding patient index.

Multipurpose Arthritis Center: Education—Arthritis Patient Education Model; Medical Allied Health Professions Integrated Curriculum in Arthritis; Arthritis Rehabilitation Training Program for Industrial Managers; Disability Determination of Arthritis

Brenda Devellis; Marlys M. Mitchell; Charles P. Friedman; Paul Leung
University of North Carolina at Chapel Hill, Chapel Hill, NC 27514

Sponsor: *National Institutes of Health*

Purpose—The UNC-CH Multipurpose Arthritis Center (MAC) represents a broadly based, coordinated effort by faculty and staff in the Schools of Medicine, Nursing, and Public Health to develop new basic knowledge, enhanced education, and improved mechanisms for health care delivery in arthritis. Providing special impetus and support in this regard are the following: Area Health Education Centers Program; NC Rehabilitation Network; UNC Rehabilitation Program; the ongoing Arthritis Rehabilitation in Industry Program; and the NC State Arthritis Act and its legislated planning committee. Certain new directions in an already well-established immunology research program will be pursued, e.g., study of the idiotype/anti-idiotypic network in human autoimmune disease, analysis of tissue deposited immune complex function in SLE, and the establishment of an immunoreagent/immunoassay core facility.

The major thrust of MAC-proposed activi-

ties, however, concerns a series of innovative projects in the education and community components. These include: 1) study of a new psychosocial model for patient education; 2) development of educational models in arthritis for occupational and physical therapists, both as part of a core undergraduate curriculum, and also in the community for those already in practice; 3) development of a health care model for ambulatory elderly patients with arthritis to be conducted jointly by nurse practitioners and occupational therapists; 4) analysis of the Social Security Administration disability determination process for arthritis; 5) development of a model training program in arthritis and rehabilitation for industrial managers with applicability to the general problem of the worker with arthritis; and 6) an epidemiologic study of patterns of arthritis care in Eastern North Carolina. In all of these projects, particular emphasis has been placed upon effective evaluation, which will be aided by an evaluation core.

Robert B. Brigham Multipurpose Arthritis Center: Feasibility Study—Evaluation of Total Knee Replacement by Gait Analysis; Community Component—Social Security Disability Study

Sheldon R. Simon and Matthew H. Liang
Brigham and Women's Hospital, Boston, MA 02115
Sponsor: *National Institutes of Health*

Purpose—This grant is requested to develop three areas of special interest. The first is applied research in which we aim to: 1) develop a necessary and sufficient database for the rational planning of health services to arthritics; and 2) develop and evaluate model components of cost-effective health care delivery for arthritis patients. Thus, under community component, we propose to develop and critically evaluate: a seven-day rehabilitation work schedule; a model health care system for arthritis disability; stepped-up rehabilitation services to homebound patients; a system of follow-up of rheumatic disease patients discharged from a tertiary care facility; a patient-oriented strategy to improve clinical outcomes; and an educational strategy for the primary prevention of low back injuries in the work place.

As one of the four major joint replacement centers in the world, we propose to evaluate the cost-effectiveness of joint replacement by a multidimensional outcome assessment. We seek to document the economic burden to arthritics and shortfalls in the present health care reim-

bursement scheme. We also propose to evaluate the means by which interventions can be evaluated by comparing the relative merits of existing health status functional instruments.

The second priority is the development of a core unit for quantitative research methods, clinical epidemiology and evaluation research, which would overlap with many activities of the center and would aid investigators in training and establishing investigators. The unit would support at least 10 projects, from the day-to-day management of special disease registries to clinical studies directed at improving clinical strategies and registries to clinical studies directed at improving clinical strategies and decision-making in rheumatology, and applications of basic research.

Finally, we propose pilot studies in a neglected area of research, the management of severe rheumatoid arthritis patients who have failed all conventional therapy; thus, the protocols addressing the critical evaluation of total nodal irradiation therapy and leukapheresis therapy of refractory rheumatoid arthritis.

Study of Behavioral Aspects of Rheumatoid Arthritis

Kenneth A. Wallston
Vanderbilt University, School of Nursing, Nashville, TN 37240
Sponsor: *National Institutes of Health*

Purpose—The long-term objective of this project is to gain a fuller understanding of the behavioral aspects of rheumatoid arthritis (RA), a chronic condition that affects more than 5 million persons in the United States and is a leading cause of disability. The major question to be explored is: Why and how do some persons with RA manage to cope very effectively with this disease while others appear to become helpless in the face of it? Specifically, this investigation aims to 1) investigate longitudinally

the health and illness behaviors of a samples (panel) of persons with RA; and 2) to determine the extent and developmental course of learned helplessness and active coping in persons with this condition.

This investigation will lay the groundwork for future interventions aimed at helping persons with RA cope with their illness. A panel of 360 patients with RA ranging from those newly diagnosed to those who have had the condition from 5 to 6 years will be studied at six-month

intervals over a 3-to-3.5-year-period via mailed questionnaires and/or telephone interviews.

Progress—Among the instruments already developed for this project are measures of arthritis-specific attitudes, locus of control beliefs, depressive affect, values, health and illness behaviors, and functional capacity. These measures will be administered repeatedly over the course of the study to ascertain changes in behavior and its psychological concomitants. This design was chosen to provide data over the first 10 years of a person's history with rheumatoid ar-

thritis and its resulting disabilities.

Future Plans—Multiple regression analyses are planned to test theoretical models linking arthritis history and experience variables to indicators of learned helplessness or coping which, in turn, will be regressed upon health and illness behaviors and health outcomes. In addition to testing models, these data will provide a wealth of systematically gathered descriptive information to greatly expand our knowledge of rheumatoid arthritis.

Energy Conservation and Joint Protection in Rheumatoid Arthritis

L. H. Gerber

National Institutes of Health, Bethesda, MD 20892

Sponsor: *National Institutes of Health*

Progress—To facilitate the adoption of energy conservation (EC) and joint protection (JP) behaviors in adults with rheumatoid arthritis (RA), a workbook-based education program using behavioral modification techniques with emphasis on developing behavioral awareness and problem-solving skills was designed. To evaluate the effectiveness of this intervention, a randomized study was designed to compare traditional occupational therapy (OT) training in the NIH and EC centers (Ann Arbor, Michigan; Brigham and Women's, Boston; and Good Samaritan, Baltimore). Patients were evaluated using an activity record adapted to measure behavioral objectives, as well as ADL, joint, psychosocial adjustment to illness, and patient and family knowledge evaluations. Experimental and control patients were tested immediately before treatment, and three months and one year following treatment. Behavioral objectives included modified patterns of rest and physical activity, including increasing frequency of rest during physical activity periods, increasing time spent physically active and in preparation and planning.

Preliminary Results—A total of 28 patients from all centers were entered from March 1983 until March 1984. Three months of data on 23 patients are currently available. Findings from the activity record showed that 46 percent of the experimental and 12 percent of the control patients improved in the amount of time spent physically active ($p = 0.1$); 53 percent of the experimental and 16 percent of the control patients increased the frequency of rest during periods of physical activity ($p = 0.07$); and 50 percent of the experimental and 20 percent of the control patients increased the time spent in preparation and planning. Three months after treatment, 25 percent of the control patients increased their index of physical activity (IPA) (i.e., index of the balance between rest and physical activity) while 47 percent of the experimental patients increased their IPA.

Although the number of patients in this preliminary research study is small, the results indicate that the new program may be more effective in changing energy conservation behaviors in RA than current approaches.

Ferrographic and Biochemical Analysis of Wear Particles in Human Joints

Dana C. Mears, B.M., B.CH., D.D. S., and Christopher H. Evans

Veterans Administration Medical Center, Pittsburgh, PA 15240

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This project had two goals. The first was to use the technique of ferrography to analyze the wear particles of human synovial fluids with the aim of providing improved diagnostic and prognostic information. The second was to determine to what extent the wear particles were involved in pathophysiological processes in arthritic joints.

The ferrographic analysis has confirmed the presence of discrete populations of cartilaginous particles within the synovial fluids of human joints. Furthermore, these populations varied according to the nature of the disorders within the joint. This was best illustrated by the results obtained with knees with torn anterior cruciate ligaments. Here, a large population of very small microspheres of cartilage was recovered. Our biochemical studies suggest that these particles may be involved in the arthritic degeneration that often follows transection of this ligament.

Preliminary Results—Preliminary ferrographic studies have also shown that the pattern of particles obtained from rheumatoid fluids is quite different from those seen in non-rheumatoid fluids. Furthermore, the ferrographic analysis of fluids from prosthetic joint replacements has yielded promising results.

Wear particles activate synoviocyte cultures, promoting the synthesis of collagenase and other neutral proteinases. At least part of this response is due to the collagenous component of the particles, as this alone is active. These reactions are probably important *in vivo*, as our results have shown that intraarticularly injected wear particles or highly purified cartilage proteoglycans promote arthritic changes in rabbits' knees.

Synoviocytes activated by wear particles, or their products, secrete substances related to interleukin-1 which cause chondrocytes to degrade their own cartilaginous matrix.

XI. Low Back Pain

Low Back Pain Assessment, Prevention, and Rehabilitation

John C. Rowlingson, M.D., and Douglas E. Degood, Ph.D.

Rehabilitation Research and Training Center, University of Virginia Medical Center, Charlottesville, VA 22908

Sponsor: *National Institute of Handicapped Research*

Purpose—The goal of our program has been to improve the adequacy of present techniques of physical and psychosocial assessment of low back pain patients, especially in regard to the contribution of adequate assessment to rapid rehabilitation following injury, and the prevention of chronicity.

Progress—During the past year several projects have resulted in published and submitted papers on: 1) the development of a standardized physical examination rating scale for the quantification of somatic amplification; 2) preliminary reliability and validity testing of the Somatic Amplification Rating Scale (SARS); 3) the development of a unique paper-and-pencil

measure for assessment of a patient's attitudes and beliefs regarding chronic pain management after viewing a standardized informational videotape; 4) the prevalence of cognitive deficits in chronic pain patients with and without documented head/neck injuries; 5) the concurrent validity of patient pain drawings as an assessment tool; and 6) the utility of the Symptom Checklist-90-R as a psychological assessment instrument with low back pain patients.

Other ongoing projects include exploration of the psychophysiological correlates of improvement in low back pain patients, as well as attempting to further our use of functional assessment of physical abilities and limitations, especially in regard to worksite requirements.

Biomechanics: Effects of Low Back Pain Treatment Modalities on Lumbar Facet Loading

Avinash G. Patwardhan, Ph.D.; Mark Lorenz, M.D.; James B. Boscardin, M.D.; Gary W. Knight, M.S.
Veterans Administration Medical Center, Hines, IL 60141

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—A majority of those who comprise the working population in the United States will suffer from low back pain and sciatica at some time in their lives. Many times, these symptoms are secondary to derangements of the lumbar intervertebral disc. A common accompaniment to disc disease is facet arthropathy.

Treatment options for lumbar disc disease include discectomy and chymopapain injection, which alter the load-bearing behavior of the disc. Clinical and experimental evidence indicates that an alteration in the mechanical behavior of the disc produces loss of alignment, abdominal movement, and loading of the facet joints. The resulting changes may lead to pro-

gressive degeneration of the facets, development of osteoarthritis, and back pain.

The objective of this study is to obtain data describing alterations in loadbearing characteristics of facet joints of lumbar spine segments following simulated treatment modalities for lumbar disc disease. During this study we will test cadaver spine specimens as a function of treatment modalities and physiological load types for various lordotic configurations of the lumbosacral spine. We will also measure facet joint loads using a pressure-sensitive film inserted between the articulating facet surfaces at L3-4, L4-5, and L5-S1 segments before and after discectomy or chymopapain injection at

L4-5 disc. With data, we will have a rational basis for designing clinical trials for physicians to use in choosing between two effective treatments, especially in cases of patients with pre-

existing pathology in facet joints. The data will also help to establish guidelines for prescribing post-treatment activities in such patients.

Myoelectrical Assessment of Human Lumbar Muscle Function

Vert Mooney, M.D.; George V. Kondraske, Ph.D.; Tom G. Mayer, M.D.; Timothy W. Carmichael, M.S.; S. Deivanayagam, Ph.D.

University of Texas Health Science Center at Dallas, Dallas, TX 75235 and University of Texas at Arlington, Arlington, TX 76019

Sponsor: VA Rehabilitation Research and Development Service and Division of Orthopaedics, University of Texas Health Sciences Center at Dallas

Purpose—The purpose of this project is to develop and investigate objective quantitative measures of lumbar muscle function for patients with low back pain, and to provide research results and measurement techniques to enable easy use of these techniques in the clinic. Equipment and techniques have been developed in this laboratory for measurement and analysis of the frequency power spectra of myoelectric signals obtained during exercise.

Progress—Myoelectric data from the erector spinae muscles of a group of 40 normal subjects performing isometric extension exercises on a back-testing device have been collected to form a normal database. Thirty-six patients with low back injuries have been tested repeatedly during rehabilitation therapy using similar protocols. In addition, a single subject series of experiments have been performed to evaluate sources of variability in EMG spectral analysis fatigue rate measures. Finally, another set of normal data has been collected for trunk rotation exercises.

Several myoelectric frequency slope measures were shown to correlate with the isometric exercise load level. Significant improvement of the correlation between the fatigue measures and the load level has been obtained by expressing the load as a percent of body weight, as opposed to percent MVC, and by using the mean actual force output over the trial (as opposed to target force) to compute the percent body weight measure.

Preliminary Results—Using the preliminary

normal database, a strong correlation was observed between fatigue rate and load levels, when appropriately expressed. This curve, representing the first step toward defining normal erector spinal fatigue rates in isometric extension exercise, was used to compare the measured fatigue rates of a preliminary group of low back pain patients with expected normal values for the measured load level during exercise. These patients work at far lower load levels (approximately 20-30 percent body weight for 50 percent MVC) than normal patients, and exhibit somewhat higher than expected fatigue rates at these levels.

Experiments to explore the effects of perturbing isolated potential sources of variability of fatigue rate measure, while controlling others, were performed on a single healthy normal subject to eliminate intersubject variability. Variation in rest time between exercise trials and trial duration time were shown to significantly affect measured fatigue rates. Results indicate that all factors must be carefully controlled in group or single-subject applications in order to obtain meaningful results. In particular, trial duration can affect values for linear slope measures of spectral shift.

Myoelectric spectral analysis studies of normal subjects, performing isometric and isokinetic right and left torso rotation exercises on a prototype rotation unit, were carried out to determine which muscle groups participate in trunk rotation and to what extent. Published results based on EMG measures show that abdominal obliques were more consistent in providing torsional moment to the spine than were

the erector spinae.

Future Plans—Work is advancing in the development of a dedicated clinical instrument for performing power spectral analysis of myoelectric signals, and in the assembly of a solid normal database for low back pain patient data

to be collected and compared. Work also continues to refine basic measures of fatigue rate derived from frequency slope measures and load level in the complex musculature of the back to obtain an accurate absolute measure of fatigue characteristics.

Surgery for Severe Spinal Deformity and Back Pain

J.H. Evans, Ph.D., and J.P. O'Brien, M.D., Ph.D.

University of Strathclyde, Bioengineering Unit, Glasgow G3 ONW, Scotland

Sponsor: *None listed*

Purpose—As part of a program which seeks to apply biomechanical analysis and new technologies to spinal surgery, two new techniques are being explored: simultaneous combined anterior and posterior fusion (SCAPF) and a modification to the Luque procedure.

SCAPF is advocated for severe, unremitting low back pain either as a primary or salvage procedure, particularly in cases with nerve root involvement. Based on biomechanical and anatomical studies, the procedure provides significant opening of narrowed lateral foramina, early weightbearing, and rapid fusion via internal fixation.

Progress—An interbody graft, of autologous or mixed autologous and bank bone, is inserted via the retroperitoneal, anterior route. This is

followed immediately by posterior distraction with Knodt or Harrington rods that anchor, bilaterally, onto the appropriate laminar superiorly and inferiorly onto the alar or a transverse pin located by the ilia. A conventional posterolateral graft completes the procedure.

The Luque procedure, which employs prefashioned rods, has been modified by the utilization of self-locking nylon straps in place of the conventional malleable metal wires. As a result, the operating time can be halved, segmental loading is both uniform and predetermined, and the incidence of neurological complications is reduced. No breakages have been encountered during surgery or subsequent to surgery. Radio-opaque straps appear promising and have been manufactured on a limited basis.

Personality Characteristics and Their Effect on Post-Surgical Adjustment

Neil Kahanovitz, M.D., and Sherri Weiser, M.A.

Hospital for Joint Diseases, Orthopaedic Institute, New York, NY 10003

Sponsor: *Hospital for Joint Diseases, Orthopaedic Institute*

Purpose—The role of personality characteristics and psychological factors in relation to the low back pain syndrome has been of interest for many years. It is becoming increasingly evident that personality characteristics are predictive of a patient's adjustment and may have more of an influence than traditional variables such as duration of illness, disability status, and socioeconomic factors. The purpose of this pilot study was to investigate the relationship

between personality characteristics and post-surgical adjustment.

Progress—Subjects in this study were 15 post-surgical low back patients (6 males and 9 females) ranging in age from 27 to 66 (mean age 42.5). All subjects had the same surgeon. Six months postoperative subjects were given questionnaires to assess his or her personality (hardiness scale), self-assessment of condition (se-

mantic differential scale), coping (Lazarus' Ways of Coping Checklist), and adjustment.

The hardiness factor is a composite of three personality characteristics: commitment, control, and challenge. Persons scoring high on hardiness are committed to life rather than feeling alienated; believe they are in control of life events; and regard change to be a challenge rather than a threat. The semantic differential scale measures the patient's assessment of his or her condition by asking the patient to rate his or her feelings about the injury on a 7-point scale choosing between two polar adjectives. The Lazarus' Ways of Coping Checklist has the patient choose between problem-focused strategies and emotion-focused strategies. Adjustment was measured in four ways: subjective pain rating; downtime; activity impairment; and general psychological well-being (Bradburn Well-Being Scale). Demographic data were collected on all patients.

Preliminary Results—Results showed the expected relationship between certain demographic variables and adjustment measures. Income

was negatively related to pain rating and activity impairment was negatively correlated with time since onset and income. Hardiness was found to correlate negatively with activity impairment and positively with psychological well-being. Coping style had no effect on any measure of adjustment.

In all four areas of adjustment there was a consistent trend. Subjects high in hardiness with positive assessments showed the best post-operative adjustment, while those low in hardiness with negative assessment had the poorest adjustment.

The results of this pilot study indicate that personality measures of hardiness and self-assessment may be predictive of post-surgical adjustment. These tests have the advantage of being easy to administer and they take a short time to answer. This test battery may be an additional tool to aid in the rehabilitation of the low back pain problem patient about to undergo surgery. The preliminary results of this pilot project provide a model with which to conduct ongoing research.

Chronic Pain Mechanisms and Manifestations: Psychological Treatment for Chronic Back Pain

Judith Turner

Department of Anesthesiology, School of Medicine, University of Washington, Seattle, WA 98195

Sponsor: *National Institutes of Health*

Purpose—Chronic pain is a major source of human suffering and a major economic problem in American society. Because the problem has long gone unrecognized, there has been little research on which to base improvements in pain patient management.

We propose to carry out seven interrelated research projects involving varying disciplines that will shed light on the mechanisms of pain, the development of pain chronicity, the clinical manifestations of chronic pain, and the treatment of chronic pain. These consist of two studies to be done on the Clinical Pain Service, an additional study of chronic pain patients, and

four laboratory investigations. Two of the laboratory studies will employ animal physiology, the third is an animal pharmacology project, and the fourth will investigate chronic pain patients in a human subjects laboratory.

In order to accomplish this we will establish a multidisciplinary network of scientific interchange, collaboration, and resource sharing that is intended to enhance and expedite the work done under each of the individual projects. Interchange among project leaders will be both formal and informal, and will include monthly project seminars and semiannual consultation visits by outside scientists.

ND: YAG Laser Effect on Spinal Discs and Nerves

Warren C. Boop, M.D.

Veterans Administration Medical Center, Little Rock, AR 72205

Sponsor: VA Rehabilitation Research and Development Service

Progress—The initial phase of the project was designed to determine the effectiveness of the ND:YAG laser in vaporizing intervertebral discs. This resulted in a disappointing amount of charring and heat buildup in the adjacent tissues, with documented pathologic changes noted.

An adaptation of the system utilizes a fiberoptic system with a synthetic sapphire tip to allow direct contact with the disc material. This adaptation allows much lower power utiliza-

tion, less heat production, and much less heat buildup in tissue. This system has been used in acute experiments with dogs and pigs.

The third phase of the experiment is beginning in which chronic animals will be studied. The fiberoptic contact point is introduced percutaneously under fluoroscopic control to vaporize the intervertebral disc. Follow-up studies will determine whether or not this system may be utilized for percutaneous vaporization of discs in humans.

A Comparative Analysis of Electrical Stimulation and Exercise to Improve Trunk Strength and Endurance in the Adult Female

N. Kahanovitz; M. Nordin; M. Parnianpour; S. Yabut; N. Greenidge; K. Viola; M. Mulvihill

Hospital for Joint Diseases Orthopaedic Institute and Mount Sinai School of Medicine, New York, NY 10003

Purpose—The nonsurgical treatment of low back pain remains a controversial area. Advocates of both flexion and/or extension exercise programs have claimed success in the treatment of low back pain. It is, however, still unclear whether any low back pain exercise program can effectively improve trunk muscle strength and endurance. Electrical muscle stimulation is used in the rehabilitation of weak or injured muscles of the extremities, but its use in improving trunk muscle strength has not been reported.

A prospective study was designed to determine whether a low back exercise program or electrical stimulation treatments were equally effective in increasing normal isometric/isokinetic strength and endurance of the trunk muscles. It was also designed to determine whether exercises, or either of two different electrical stimulation parameters, were more effective in increasing the various strength parameters.

Progress—Subjects were 114 normal females between the ages of 18 and 48 (mean of 29 years) with an average weight of 57 kilograms

and an average height of 160 centimeters. None of the subjects had a recent history of low back pain and each was examined by an orthopaedic surgeon prior to participation in the study. Each subject's strength and endurance was determined by a standard test battery administered before and after treatment. The battery consisted of Cybex isometric and isokinetic evaluation of flexor and extensor trunk muscles, Natick standing pull tests, and Sorensen's endurance test. All testing was randomized except the Sorensen test, which was always performed last. Four randomized study groups were formed, consisting of two electrical stimulation groups (32 subjects in group 1 and 29 subjects in group 2), an exercise group (31 subjects), and a control group (22 subjects). Each group was comparable in terms of average age, weight, and height.

The exercise and electrical stimulation groups underwent treatment sessions lasting 30 minutes, 5 days-a-week for 4 weeks. The control group received neither exercise nor electrical stimulation treatments. Subjects receiving electrical stimulation treatments were prone with

two surface electrodes placed at the L2 to L4 levels bilaterally over the erector spinal muscles. A low voltage (45V), low frequency (35 Hz), muscle stimulator with a biphasic, symmetrical balanced rectangular pulse was used for group 1. A higher voltage (0-105 V), midrange frequency (300-500 Hz) muscle stimulator with a spike wave was used for group 2. The exercise group had a 5-minute warmup and cool-down period of stretching with 20 minutes of strengthening exercises.

Following the completion of post-treatment, data were subjected to an analysis of variance, and a T-test was used to establish significance. There was no significant improvement in isometric strength or in the Natick pull test in any of the groups compared to one another or to the control. A statistically significant ($p < .02$) increase was found in isokinetic strength in both the exercise group and the electrical stimulation group 1, compared to the control group. Electrical stimulation group 2 showed no significant increase in isokinetic strength parameters compared to the control group. There was no significant advantage, however, in strength improvement between the electrical stimulation and exercise groups. The electrical stimulation groups showed significant ($p < .02$ in group 1; $p < .05$ in group 2) increase in endurance compared to both the exercise and control groups. This was shown both by an increase in holding time as well as in total energy expended. Comparison of the two electrical stimulation groups indicated that the low-voltage, low-frequency

stimulation was more effective in improving isokinetic strength than the higher-voltage, mid-range, frequency stimulation.

Preliminary Results—The results of this study indicated that neither exercise nor electrical stimulation increased all parameters of strength. Neither electrical stimulation nor exercise appear to significantly improve isometric strength in a 4-week program. Stimulation and exercise are, however, both comparable in increasing isokinetic strength. In addition, electrical stimulation appears to be superior to exercise in improving endurance.

This study showed that electrical stimulation is applicable in the rehabilitation of the low back pain patient with decreased strength and endurance. It may be particularly useful in the patient with acute and subacute low back syndrome because of the passive nature of the stimulation as well as the concomitant TENS effect. However, it should be recognized that both exercise and electrical stimulation do not effect every measurable strength parameter in a similar way. Once recognized, selective training with electrical stimulation, exercise, or a combination of both are necessary for optimal results.

We are presently conducting a study using as subjects patients who are 4 to 6 weeks post-one-level disectomy. They are randomly placed in either a control group, an exercise group, or an electrical stimulation group.

XII. Muscular Dystrophy

A Study of the Mechanism of Spinal Collapse in Duchenne Muscular Dystrophy _____

Greg Noone, M.Sc.; Jagan Mazumdar, Ph.D.; Barry R. Seeger, Ph.D.

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009, Australia

Sponsor: *Regency Park Centre for Young Disabled*

Progress—A simple model consisting of a slender beam and support wires was constructed as an initial first model of the spine and its muscles. This model could give an indication of the sets of applied forces and/or moments that will restore as much as possible the spinal configuration. The model is solved by forming the stiffness matrix of the structure, K , and solving the load-displacement equation $P=Kd$. The difficulty is in accurately deducing the appropriate input data that would resemble the properties of the spine.

Data from literature give the stiffness matrix for some intervertebral joints (minus muscles). Therefore, it should be possible to form an approximate stiffness matrix of the whole column (minus muscles) and then form a

modified stiffness matrix by including muscles modelled as springs or wires. Compare the results with the slender beam and support wires model. There is, however, a wide variation in stiffness matrix data from the literature. We are also modelling the spine by an anisotropic beam supporting a rigid body. We will look at the effect of a tilted pelvis and varying rigid body positions in a muscle-relaxed position, considering first only lateral bending, and deduce the equilibrium positions of the spine. Generally, we could expect three equilibrium positions. The model will be generalized and refined to include kyphotic curvature and sagittal bending, external and internal loads, and constraints of movements.

Forearm Levitation _____

Ray Gick; Walt Alford; John Staehlin

MSME Westinghouse Defense and Operations Division and Volunteers for Medical Engineering, Inc.,
Lutherville, MD 21093

Sponsor: *None listed*

Purpose—A mechanism has been designed by the Volunteers for Medical Engineering Inc. (VME) which supports the forearm of a person who does not have enough strength to raise it without some help. The device essentially levitates the arm, closely counter-balancing its weight so that only minimal force is required to raise or lower the arm.

The original design was made for a young man with muscular dystrophy and he has agreed to evaluate it for the VME.

Progress—The overall layout of the mechanism has been completed and the detail drawings for

the fabrication of the prototype are under way. The fabrication was started in July 1986 and the first prototype was ready for testing in the fall of 1986.

Preliminary Results—A preliminary analysis of the mechanism is complete. A more detailed structural analysis will be started shortly and will be completed in time for iteration of the design before the unit fabrication is complete.

The detailed purchased parts list is complete and orders will be placed for two assemblies, enabling the VME volunteers to have a unit for continuing evaluation while the client

is using the second unit.

Future Plans—The unit now being fabricated is custom made for the client and will be useable only for others whose needs are similar and whose size and weight are similar. It is our goal to have the design computer database iterata-

ble so that customization may be accomplished in a timely manner and the details rapidly updated for the new configuration. This would be readily accomplished because the present database is on the Interactive Graphs (IAG) computer system.

The Role of Spinal and Abdominal Muscles as Etiological Factors in Scoliosis in Neuromuscular Disorders

L.M. Stern, M.B.B.S.; and B.E. Clark, M.B.B.S.

Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: *Regency Park Centre for Young Disabled*

Purpose—The purpose of our study is to determine whether computerized tomography of spinal and abdominal muscles in the dorsal and lumbar regions can be correlated with the degree of spinal curvatures in the neuromuscular disorders of Duchenne muscular dystrophy and spinal muscular atrophy, and whether this can be a prognostic indication of severity and speed of development of scoliosis.

Progress—There is a difference, in the pattern of muscle loss and/or replacement with either fat or fibrous tissue in both spinal and abdominal muscles, between boys who sit with a straight spine or a lordotic stance and develop only minimal scoliosis and those who are more kyphotic and develop severe scoliosis. This difference is detectable on C.T. scans.

The course of Duchenne muscular dystrophy is one of relentless progression of all voluntary muscles. While the subjects remain ambulant, there is an increase in the lumbar lordosis which is related to the weakness of the pelvic girdle musculature and a shift in center of gravity. Between the ages of 8 and 12, the children may cease to ambulate and become wheelchair bound. From this time, the greater proportion of them will develop a scoliosis or a kyphoscoliosis. In the case of spinal muscular atrophy, scoliosis is usual and may occur earlier or later according to the severity of the child's condition.

Preliminary Results—While the etiology of sco-

liosis in neuromuscular disorders has not been elucidated, it has generally been attributed to asymmetrical weakness of the muscles which support the spine. Wilkins and Gibson ("The patterns of spinal deformity in Duchenne muscular dystrophy." *J Bone and Joint Surg* 58-A, 24-32, 1976) in the clinical and roentgenographic study of 62 patients with Duchenne dystrophy observed that some patients with hyperextended spines had comparatively little scoliosis, while those who sat with a kyphotic posture tended to develop severe scoliosis. At the Regency Park Centre we have confirmed these findings clinically over a number of years.

Further work by Koreska et al. ("Biomechanics of the lumbar spine and its clinical significance." *Orthopaedic Clinics of North America* 8, 121-133, 1977) on the biomechanics of the lumbar spine and its clinical significance suggested that locking the posterior facets by trying to induce a "built in" lordotic posture in a wheelchair would reduce or prevent scoliosis. This latter hypothesis has not stood the test of time, however, and further work by Seeger & Sutherland ("Lumbar extension in Duchenne muscular dystrophy: Effect on lateral curvature." *Arch Phys Med and Rehabil*, 66, 236-238, 1985) did not support that finding. Earlier work by Stern et al. ("Progression of muscular dystrophy assessed by computed tomography." *Developmental Medicine and Child Neurology*, 26, 569-573, 1984) has shown that computer tomography is an accurate means of detecting the changes in dystrophic muscle and over a longi-

tudinal period of time can accurately reflect the changes in the muscle.

Future Plans—We propose to include 20 subjects with Duchenne dystrophy or spinal muscular atrophy in the study. Two scans will be taken, one through the dorsal region and one through the lumbar region. This gives good access to spinal and abdominal muscles. Density readings would be taken on both sides and compared. The density readings are a good indi-

cation of loss of muscle fibres. In each case the readings will be correlated with the degree of spinal X-rays which have already been taken to monitor the scoliosis. Similar readings would be repeated in 12 months to monitor the changes in the muscles.

It is hoped that these observations will produce some insight into the etiological factors of the scoliosis, and possibly suggest new strategies to approach the problem of prevention and treatment.

A Random Crossover Trial of Respiratory Muscle Endurance Training in Duchenne Muscular Dystrophy

L.M. Stern, M.B., B.S.; A.J. Martin, M.B.ChB; B.R. Seeger, Ph.D.; R.E. Garrett, B. Tech., Grad. Dip. Maths.; N. Jones, B.E.

Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: *Channel 10 Children's Medical Research Foundation and the Utah Foundation*

Purpose—The aim of the project is to test the hypothesis that regular ventilatory muscle training over sufficiently long periods will show statistically significant improvement in ventilatory muscle endurance in children with Duchenne muscular dystrophy. It is proposed to carry out the ventilatory muscle training by the use of computer games which will be adapted to be activated by the inspiratory efforts of the subjects.

Improvement of ventilatory muscle endurance could, in the longer term, lead to a slowing in the rate of pulmonary function deterioration, which occurs in Duchenne dystrophy, and delay the onset of respiratory failure.

Progress—The Electrical Engineering Department of the University of Adelaide has developed a means of monitoring the degree of

breathing effort (or air velocity) during a training session. This unit uses a thermistor in a tube through which the person breathes. In order to keep the children's interest up, they will be able to play video games for as long as they breathe hard enough. If they do not satisfy this criterion, the joystick controlling the game will be temporarily disconnected. A bar of light-emitting diodes indicate how well the children are doing and how close they are to be disconnected.

The 15 boys involved in this study will be divided into two study groups with one group playing the video games and the other not. This situation will be reversed after 6 months. Each individual will have pulmonary function tests including measurement of inspiratory endurance at the beginning of the trial, at 6 months, and at 12 months.

XIII. Sensory Aids

A. Blindness and Low Vision

1. General

An Auditory Data-Flow Indicator for the Blind

Arthur Jampolsky, M.D.; J.A. Brabyn, Ph.D.; Deborah Gilden, Ph.D.

Rehabilitation Engineering Center, The Smith-Kettlewell Eye Research Foundation, San Francisco, CA 94115

Sponsor: *National Institute of Handicapped Research and The Smith-Kettlewell Eye Research Foundation*

Purpose—When a blind person is transmitting or receiving data over an RS-232 serial interface connected to a modem, printer, or other device, he often has difficulty in ascertaining whether the data flow is proceeding normally, and whether the transmission has ended. In response to inquiries from blind computer users regarding this problem, we have developed a simple auditory data-flow indicator, consisting of an appropriate audio transducer connected directly into a standard RS-232 interface cable, and driven from the data signals. The device indicates to the user when data transfer is in

progress, aiding him in knowing whether the interface to printers and other peripherals is working normally and when the computer is free to receive other input. The indicator device is especially useful with modem operations, for alerting the user when a long data transmission has finished.

Results—This device, after evaluation by the Kentucky Bureau for the Blind, is now being produced commercially under the name of "Tweedle-Dump."

Auditory Breakout Box

Arthur Jampolsky, M.D.; J.A. Brabyn, Ph.D.; Deborah Gilden, Ph.D.

Rehabilitation Engineering Center, The Smith-Kettlewell Eye Research Foundation, San Francisco, CA 94115

Sponsor: *National Institute of Handicapped Research and The Smith-Kettlewell Eye Research Foundation*

Purpose—Although standards theoretically exist for the interconnections between computers and peripherals, it is well known that individual usage varies considerably. Sighted individuals have access to breakout boxes which can be connected between the computer I/O port and a peripheral. Each input signal line can be connected, through the use of jumpers, to any output line, and the device indicates (through activation of LEDs) when the correct connections have been made. In order to provide the same capabilities to blind individuals,

we have developed an auditory version of the breakout box.

Progress—This version provides the same capabilities as a normal breakout box, allowing different connection combinations to be tried out conveniently, but utilizing a tonal sound-coding system to indicate whether any selected line is grounded, high, low, or open. In an improved version of the device, recently completed, the jumper connectors for the input and output lines are fabricated from banana plug sockets

at quarter-inch spacings, to facilitate easy tactile location of any desired input or output line.

Preliminary Results—The first prototype has

been successfully tested in practical use by several blind users, and means are now being sought for transfer of the device to commercial production.

Pediatric Vision Screening

Arthur Jampolsky, M.D.; J.A. Brabyn, Ph.D.; Deborah Gilden, Ph.D.

Rehabilitation Engineering Center, The Smith-Kettlewell Eye Research Foundation, San Francisco, CA 94115

Sponsor: National Institute of Handicapped Research and The Smith-Kettlewell Eye Research Foundation

Purpose—Among infants and children, the major causes of visual impairment are strabismus and amblyopia, which affect approximately 3-5 percent of all infants. One million ophthalmologists visits per year are related to strabismus. In addition, it has been estimated that approximately 15,000 children in the U.S. are born with or develop cataracts in early infancy. Infantile cataracts differ from adult cataracts in that they produce a sensory deprivation during development, which leads to permanent sight loss if the cataracts are not removed very soon after they appear.

These conditions fortunately respond well to simple rehabilitative measures if detected early enough. However, conventional vision testing methods that require verbal responses are obviously unsuited to this population group. Thus, means of early detection of such conditions are urgently needed so that early intervention can prevent permanent handicaps. Clearly, maximum human benefit as well as cost-effectiveness in rehabilitation would be realized if methods could be found to detect and reverse blinding conditions as soon after birth as possible.

Progress—A simple photographic mass screening technique for several common ocular anomalies that can seriously affect vision has been under engineering development. The concept of this device derives from that underlying the retinoscopes and ophthalmoscopes commonly used by clinicians to diagnose diseases and anomalies of the eye; a camera system has been developed which mimics the action of these instruments. The system does not require the skill involved in using a retinoscope or ophthal-

moscope, and it produces a permanent, readily interpreted record of the state of both of the eyes. As such, it should be suitable for mass screening of ocular anomalies by non-eye care specialists.

The technique is easily applied in even the youngest infants, and requires only a small amount of training for the operator. We envision that this system, which is made of standard photographic equipment, could be placed in pediatricians' offices and in hospital nurseries for use by hospital staff in screening infants at well-baby clinics. Children with abnormal photorefractions would then be referred to the appropriate eye care specialists.

The camera system consists of a 35-mm camera with a 500-mm mirror telephoto lens. An electronic flash is placed immediately adjacent to the margin of the lens which forms the entrance pupil of the camera's optical system. Light from the flash is refracted by the lens of the eye, once upon entering the eye and again upon leaving the eye after being reflected from the fundus. The refractive state of the eye, as well as the presence of media opacities such as cataracts, affect the image returned from the eye that is recorded on film.

For example, the presence of a bright band at the top of the pupil in an infant with a significantly different refraction between the two eyes indicates that the eye is hypermetropic or farsighted, and the size of the band indicates the magnitude of the error. A band is not visible if there is no refractive error in that eye. We are developing a geometrical optics model of the camera and eye which can accurately predict the size of the bright band as a function of the magnitude of the refractive error and the

size of the eye and pupil being photographed.

The technique will be validated in several

clinicians' offices before larger scale screening studies are undertaken.

Assessment of the Spatial and Temporal Characteristics of Vision as a Function of Age

Edward J. Rinalducci

Veterans Administration Medical Center, Decatur, GA 30033

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The main objective of the research reported here was to examine changes that occur in the spatial and temporal properties of the human visual system as a function of the aging process. It was proposed that data of a preliminary nature be gathered on spatial contrast sensitivity and visual persistence for a group of young adult observers (18-29), middle-aged (30-49), and older observers (50-75).

Due to delays caused by funding and equipment purchases, it was decided that much useful normative information could be gained by employing the following tests with the age groups of interest: 1) the Vistech Contrast test; 2) the Keystone Optical Tester; 3) the Ishihara Color Vision Test; 4) the Tritan plate (F2) test developed by the Naval Medical Submarine Research Laboratory-New London; and 5) the Munsell-Fransworth 100-hue test.

The Vistech Vision Contrast Test was used to obtain a rapid assessment of spatial contrast sensitivity for each subject. The results could then be compared to a measure of Snellen acuity obtained with the Keystone Optical Tester. The contrast sensitivity test and the Snellen acuity test were chosen so as to give an assessment of spatial vision together with visual resolution.

The color vision tests were chosen (especially the Munsell-Farnsworth 100-hue test) so as to examine changes in color discrimination with age, particularly in the short-wavelength end of the visible spectrum. A standard color

screening test (Ishihara) was included in order to identify those observers with red-green color deficiencies and the F2 test was used to identify those individuals who may be tritanopic or tritanomalous. Data for the young adult observers have been collected (about twenty in all) and analyzed. Few significant departures from normal functioning were obtained with the young adult group. Differences are expected for the older observer population.

The middle-aged and older groups of observers will be run in the next few weeks. It is anticipated that at least 20 subjects will be run for the older observer group. The middle-aged observer group will be chosen largely from the faculty of Georgia Tech.

Visual persistence will be measured by flickering a grating of a given spatial frequency (e.g., 1, 3, and 12 Hz) at a rate which is just fast enough to be seen as fused (i.e., until a critical fusion level is obtained). This technique should allow rapid and relatively easy collection of data using older observers. A test for visual persistence should be useful for determining spatio-temporal changes in the visual system with age, and as a test of the persistence theory which predicts longer lasting effects of a stimulus in the older as compared to younger nervous systems.

Based on the analysis of the data from the above test, recommendations could then be made with regard to adequate vision under normal and adverse conditions.

The Effects of Preview Distance on Blind Mobility

Rebecca Hollyfield, Ph.D.

Veterans Administration Medical Center, Hines, IL 60141

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of this research project was to establish boundaries for the effective preview distance for blind pedestrians. Using an ultrasonic ranging device, we did this by systematically varying the preview distance for a group of experienced, blindfolded travelers walking over a predetermined course six times.

Progress—The first time the group walked over the route, we used no preview device and placed no movable obstacles on the route. This trial familiarized the traveler with the route and gave baseline data on walking speed, step length, cadence, etc. In the remaining trials, we

placed movable obstacles randomly along the route, and each subject had the preview device along.

For the test, we used a modified version of a Polaroid ultrasonic ranging device, setting it to a predetermined preview distance for each subject in each trial. This distance varied from one to ten feet. Half of the subjects had increments of even distances (2,4,6,8, and 10 feet) and half had odd distances (1,3,5,7 and 9 feet); also half of the subjects had ascending preview distances over their five trials and half had descending distances.

The Elderly Blind Client: Factors Associated with Employment Outcome

J.M. Giesen, Ph.D. and K. Ford, M.S.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: National Institute of Handicapped Research and Mississippi State University

Purpose—The American population is growing older, and blindness is much more prevalent among the elderly. The purpose of this study was to assist vocational rehabilitation agencies serving elderly blind and visually impaired persons in program planning and allocation of agency resources targeted specifically to increase successful employment closures of elderly blind persons.

Progress—A review of literature and empirical research were the means. This study identified factors that were associated with four client employment outcomes: competitive employment, sheltered workshop employment, home-maker closures, and unemployed closures. The categories of factors used to predict employment outcome of elderly blind clients included rehabilitation process, personal, financial, environmental, occupational, and counselor-related variables. This study utilized the 188 elderly (age 56 and over) blind cases from the MSU

RRTC Employment Database formed in previous research projects as indicated by the following summary.

Extensive data were abstracted directly from case records of 619 legally blind and totally blind clients, chosen by systematic quota sampling, closed as successful (status 26) or unsuccessful (status 28) by rehabilitation agencies in Florida, Kansas, Mississippi, and Ohio. In addition to data from the R-300 form, data were also obtained from case files on disabilities, use of aids, occupational history, expenditures, etc., forming the MSU RRTC Employment Database of over 270 variables.

This study used stepwise multiple discriminant analysis to identify which variables were best able to discriminate among the employment outcome groups for the sample of elderly blind clients.

Results—Using the 21 predictor variables identified by the discriminant analysis, a 77 percent

correct classification of employment outcome group was obtained, representing a 71 percent improvement over the chance correct classification rate. Fifty-seven percent of the significant discriminating variables for the elderly blind sample were rehabilitation process variables: expenditure for personal or vocational adjustment training, expenditure for "other" atypical services, whether restoration services were provided, total expenditure for rehabilitation facilities, expenditure for hospital and convalescence, expenditure for diagnostic evaluation, whether maintenance was provided, whether diagnostic services were received, expenditure for trade school training, skill level of the IWRP occupational goal, and total for "other" unclassified expenditures.

Biographical and disability-related variables accounted for 29 percent of the discrimi-

nating variables: whether nonoptical aids were used; age at onset of blindness, whether the client had a Spanish surname, total number of disabilities, sex, and expenditure for travel and transportation. There were two discriminating variables in the financial/disincentive category which were: 1) whether the primary source of support at referral was from personal and private sources; and 2) time on public assistance at referral. Proximity to the vocational rehabilitation counselor was the only environmental variable that discriminated the employment groups. No occupational or counselor-related variables were among the set of significant discriminating variables.

A technical report is available at a nominal fee from the Rehabilitation Research and Training Center on Blindness and Low Vision, P.O. Drawer 5365, Mississippi State, MS 39762.

Factors Influencing Employment Outcomes of Legally Blind Rehabilitation Clients Who Have Hearing Impairments

B.J. Maxson, M.Ed.; J. Martin Giesen, Ph.D.; William Graves, Ed.D.; Kevin Ford, M.S.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: National Institute of Handicapped Research; Helen Keller National Center, Mississippi State University

Purpose—The purpose of this study is to identify factors that influence the employment outcomes of legally blind clients who also have hearing impairments and are served by state rehabilitation agencies for the blind.

Progress—Multiple discriminant analysis was used to assess employment outcomes and related characteristics of 44 legally blind individuals who were closed in status "26" or "28" by rehabilitation agencies in Florida, Kansas, Mississippi and Ohio in FY 1978, 1979, and 1980. Employment outcomes were defined as competitive, sheltered, homemaker and unemployed. Variables were categorized as those related to 1) disability and biological data; 2) geographical data; 3) vocational process data; and 4) financial data.

Results—It was found that there were seven significant variables related to the employment

outcome of this sample. They were: 1) age at referral; 2) primary support at referral; 3) total services expenditure; 4) received maintenance; 5) months in status 00-02; 6) proximity to nearest sheltered employment; and 7) visual efficiency loss. There was no significant difference in the employment outcomes between this group and a larger sample of 575 legally blind clients who were not hearing impaired. Using a stepwise multiple discriminant analysis, there is a 98 percent successful classification rate for predicting the employment outcome of these hearing impaired clients based on 20 variables and an alpha of .10.

A technical report and executive summary are available through the Rehabilitation Research and Training Center. In June 1986, a Research Utilization Seminar held in Atlanta, Georgia included the reports of this study. Also, presentations are planned at the Association for the Education and Rehabilitation of the

Blind and Visually Impaired National Conference, the Helen Keller National Center Affili-

ate Conference, and other RRTC-sponsored workshops.

Prevocational Skill Acquisition of Multiply Handicapped Blind Youth Using Adapted Electromechanical Assessment Devices

B.J. Maxson, M.Ed. and Mark Haucke, M.S.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute of Handicapped Research; Helen Keller National Center, Mississippi State University*

Purpose—This project is based on the need for prevocational training and vocational evaluation readiness activities for deaf-blind and multiply handicapped blind youth. Electromechanical Vocational Assessment Technology was developed by the National Industries for the Blind based on work success skills identified as important for jobs within their shops. The equipment was further adapted and used 1) to develop meaningful prevocational and work success skills training activities; 2) as a vocational evaluation readiness activity; and 3) as a field study for empirical research on learning and transferable prevocational skills.

Progress—Activities were developed to provide teachers, vocational evaluators, and prevocational specialists with a tool to measure the acquisition of work success skills. The prevocational activities also function as effective vocational evaluation readiness exercises, to provide multiply handicapped youth with experiences similar to those encountered in a vocational

evaluation setting. The study provided recommendations for more effective use of the electromechanical work task units as prevocational learning aids.

Results—A training manual and videotape were developed for practitioners and researchers to correctly implement each work task unit and evaluate subject performance. The results indicate that subjects who successfully completed the work task units exhibited many of the necessary work success skills needed for placement in real work settings. The field study highlighted some guidelines for users of the work task units. A printed manual and supplemental videotape are available through the Rehabilitation Research and Training Center on Blindness and Low Vision. In June 1986, the results of the project were reported in Atlanta, Georgia at the Deaf-Blind Research Utilization Seminar. Presentations are planned at other RRTC sponsored workshops.

Low Vision Performance as a Function of Environmental and Stimulus Characteristics

S. Marmion, Ph.D.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute of Handicapped Research; Mississippi State University*

Purpose—The purpose of the study was to investigate the effects of several stimulus characteristics (such as illumination, contrast, size, target speed, and presentation mode) on the performance of vision impaired subjects, across various tasks related to many kinds of real world visual functioning.

Research questions included: 1) What is the relative strength of various stimulus characteristic effects? 2) To what extent do such characteristics interact with one another? 3) Are such stimulus effects and interactions consistent across differing visual tasks? 4) Are stimulus effects consistent for low vision subjects with

stimulated visual losses?

Progress—Three visual-performance tasks measuring aspects of visual functioning, such as visual search, pattern identification, and visuomotor control, were developed and administered to 1) 48 sighted subjects wearing special lenses to stimulate significant visual loss; and 2) 43 low vision clients. Tasks and variables were as follows:

1) A Landolt-C Search Task, which relates to tasks involving visual scanning (such as reading), was performed under three levels of illumination, three levels of contrast, and three target sizes;

2) A Rotary Pursuit Task, which relates to tasks involving visual tracking, was performed at two different speeds and with three levels of contrast between target and background; and

3) A Pattern Identification Task, which relates to tasks involving visual inspection, required subjects to a) identify a target letter; and b) indicate its orientation in space. Two presentation modes were employed: moving-target and stationary-target. Three contrast ratios, two background/foreground conditions, three stimulus sizes, and three levels of illumination were compared.

Results—Performance of the two groups significantly differed on all tasks, with the Simulated-Loss group performing better than the Low-Vision group. A number of interactions between stimulus variables and the group variable were obtained across tasks, which indicated that virtually all stimulus variables exerted a more potent effect on the Simulated-Loss group than on the Low-Vision group. An explanation for this finding may lie in the greater performance variability exhibited by the Low-Vision subjects. This was not unexpected, due to the greater heterogeneity of subjects in this group on such variables as age and vision characteristics of impairment.

Across tasks, the size variable had the most consistent and potent effect on both groups. Interactions between size and the other stimulus variables indicated that stimulus size becomes more critical to performance under more difficult levels of other variables (i.e., lower illumination, contrast, etc.). All stimulus variables significantly affected performance either singly or in combination with other variables on every task, especially for the Simulated-Loss group.

The project has been completed and a technical report is now available from the Rehabilitation Research and Training Center on Blindness and Low Vision.

Electromechanical Vocational Assessment Technology for the Evaluation of Industrial Work Abilities of Blind and Visually Impaired Persons

M. Bagley, M.S.; W.H. Graves, Ed.D.; S.D. Machalow, Ph.D.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute of Handicapped Research; Mississippi State University*

Purpose—The purpose of this study is to determine the reliability and validity of six electromechanical work task units designed for use as preemployment evaluation tools. The question to be answered is: Are each of the six electromechanical work task units reliable and valid preemployment assessment technologies for evaluation of blind or visually impaired production employees?

Progress—A test-retest over time design was

used on 30 subjects drawn from the following rehabilitation facilities and sheltered workshops: Mississippi Industries for the Blind, Jackson, Mississippi; Addie McBryde Rehabilitation Center, Jackson, Mississippi; Royal Maid Association for the Blind, Hazlehurst, Mississippi; Regional Rehabilitation Center, Tupelo, Mississippi; Royal Maid Association for the Blind, Tupelo, Mississippi; and Louisiana Association for the Blind, Shreveport, Louisiana.

Background data were collected on all sub-

jects tested. Data included date of birth, medical and psychological information, work history, and level of education. Additional information included relevant vocational evaluation and assessment scores: Valpar, WRAT, IQ, and the Pennsylvania Bi-Manual Dexterity Work Samples scores. For individuals who were employed at the time of testing, job analysis and supervisor ratings were obtained.

Reliability levels indicating test accuracy over time were established by computation of coefficients of stability obtained through test-retest procedures. Product-moment correlation was the primary method used. A standard error of measurement also was determined.

Data collection procedures were arranged to minimize practice effects on test-retest reli-

ability; the length of interval between testing periods, and the lack of intervening training activities, tended to reduce the impact of practice on the reliability measure.

Results— This project has been completed and a technical report was published in August 1985. Design problems necessitated early termination of data collection on two units. Good reliability results were obtained for all of the work task units. Data analyses indicate some degree of validity for the remaining four work task units. Due to the limited number of subjects, the data necessary for the validity study were difficult to obtain; therefore, conclusions regarding the validity of these reports are considered to be tentative.

Modification and Adaptation of the Vocational Education Readiness Test for Blind/Severely Visually Impaired Individuals

L. McBroom, M.A. and S. Chen, Ph.D.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute of Handicapped Research; Mississippi State University*

Purpose—In recent years vocational evaluation has been recognized as an effective procedure for determining the vocational strengths and needs of handicapped persons. The purpose of this project is to determine whether each of the Vocational Education Readiness Tests (VERT) adapted for blind and visually impaired persons is an appropriate assessment tool for determining the aptitude of these persons to enter vocational education programs in Auto Mechanics, Basic Wiring, Quantity Foods, and Industrial Sewing.

Progress—Subjects were randomly selected from the blind clients and work force of the Regional Rehabilitation Center in Tupelo, Mississippi, the Arkansas Enterprise for the Blind, and the Mississippi Industry for the Blind to serve as the sample of this project. They included 44 subjects for automechanics, 32 subjects for industrial sewing, and 35 subjects for basic wiring. Twenty cases from the Addie McBryde

Center for the Blind, Jackson, Mississippi, will be selected for an evaluation of the Quantity Foods VERT.

The demographic and visual information on these subjects was collected. Test-retest reliability of the VERT assessment tools is being established. Validity has also been assessed in the data collection process. Descriptions of the norm groups will be provided along with percentile charts used by vocational evaluators.

The motor skills tests and most of the cognitive skills tests in the automechanics work sample were found to have significant test-retest reliability and concurrent validity with VALPAR. The reading test was found to be unreliable, and the vocational terminology tests did not correlate with WRAT scores.

Data for industrial sewing and basic wiring are being analyzed. The data collection for Quantity foods was completed in October 1986. A technical report may be obtained from the Rehabilitation Research and Training Center.

Development and Validation of a Work Environment Visual Demands (WEVD) Protocol

W. H. Graves, Ed. D.; B. J. Maxson, M.S.; H. Takacs, Ph.D.; J. Adkisson, M.S.; G. Smith, M.S.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute of Handicapped Research; Mississippi State University*

Purpose—The purpose of the study is to develop a procedure to be used in analysis of the visual demands of a job held by or desired by a visually impaired person. The information may be used by eyecare professionals in prescription of low vision aids which will facilitate performance of job tasks or in modification of visual tasks required in the job setting.

Progress—Forty randomly selected, employed, legally blind individuals will be assigned to experimental and control groups. After assignment, the researcher will analyze jobs based on the Work Environment Visual Demands Protocol. Protocol information will be entered into a computer, generating a one-page report for analysis by the low vision clinic team prior to, and for use in conjunction with, a low vision examination for the experimental group. The computer report will be withheld for the control group until all subjects have been seen by the clinic one time, at which juncture the low vision team will review the information and schedule a follow-up appointment if necessary.

Information will be collected on length of examinations, reported comfort levels, frequency of visits to clinic, number of aids prescribed, and physician's notations. Multivariate analysis of variance will be used to analyze data.

A Work Environment Visual Demands Protocol has been developed. Forty randomly selected legally blind individuals who are gainfully employed have been evaluated at their work site utilizing the protocol; computer reports have been generated for the Low Vision Clinic which has seen all study participants for the initial evaluation and prescription. Software has been completed for the IBMPC.

Future Plans—Study participants in the control group will be seen with WEVD Protocol information provided to the Low Vision Clinic. Follow-up will be done on all participants. Apple IIe software will be completed. All manuals will be completed. Training will be provided for selected personnel in state agencies and private nonprofit agencies serving blind persons.

The Effects of Sensory Aids on the Employability and Career Development of Visually Impaired Persons

S. Marmion, Ph.D.; L. McBroom, M.S.; S. Machalow, Ph.D.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute of Handicapped Research; Mississippi State University*

Purpose—The purpose of the study is to determine the effects of the use of sensory aid technology on the employability and career development of blind and visually impaired persons. "Sensory aids" refers to any specially adapted electronic or mechanical device used by a visually impaired person to replace sensory information lost through the effects of visual impairment. The output of these devices is usually in

a tactile, auditory, or enhanced visual mode. Answers to the following research questions are sought:

- 1) How is technology being used to enhance the career development of blind and visually impaired persons?
- 2) What technology is being used?
- 3) What resources are being used to support the provision of sensory aids to rehabilita-

tion clients?

4) What factors are related to the provision of sensory aids to rehabilitation clients?

Progress—A survey instrument was developed that was designed to be filled out by rehabilitation counselors of the visually impaired. It asked for information concerning their educational training, caseload, and agency factors involved in provision of sensory aids to clients. It asked for further detailed information on two randomly selected clients who had received a sensory aid in the past year, including their background characteristics (visual impairment,

employment history, etc.), sensory aid usage and/or training, and the perceived impact of sensory aid usage on their employability and career development. A total of 385 surveys were sent to both public and private rehabilitation agencies for the blind, to be filled out by randomly selected counselors. Eighty-nine completed surveys were received from 32 states. Thirteen percent were received from private agencies; 87 percent from public agencies. The data from the surveys are undergoing analyses. A technical report is available from the Rehabilitation Research and Training Center on Blindness and Low Vision at a nominal fee.

Perceptions of Teachers, Rehabilitation Counselors, and Rehabilitation Administrators of the Career Development Needs of Blind and Visually Impaired Students and Adults

W.H. Graves, Ed.D.; S. Lyon, M.S.; S. Marmion, Ph.D.; K. Boyet, M.S.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute of Handicapped Research; Mississippi State University*

Purpose—The project was designed to determine the perceptions of kindergarten teachers; teachers of grades 3, 6, 9, and 12; rehabilitation counselors; and rehabilitation administrators of the career development needs of their clientele who are blind or visually impaired. Their perceptions of their own access to the services they need to meet the career development needs of their clientele were also sought.

Progress—A survey of teachers, rehabilitation counselors, and rehabilitation administrators serving clientele who are blind or visually impaired was conducted. From the surveys, factors were derived which identified the perceptions of these providers of the career development needs and career services needs of their clients who are blind or visually impaired. Factors were also derived which were used to identify the perceptions of the services the providers needed to meet the career development needs of their clients.

Results—Providers of educational and rehabilitative services to blind and visually impaired

students and adults do not perceive that the career development needs of these students and adults are being met. Additionally, these providers do not perceive that their circumstances permit them to meet the career development needs of this group of people, either in types of services or in the frequency of provision of services. The findings suggest that educational and rehabilitation services providers recognize the importance of career development service in enhancing the quality of life of people with visual disabilities. The results also suggest that schools and rehabilitation agencies need to examine exemplary career development programs for sighted people, and plan career development programs for their visually impaired clientele on the basis of those exemplary programs. The findings further suggest that the providers will need to adapt the exemplary programs to meet the special needs of their clientele which are caused by the intrinsic and extrinsic factors of blindness and visual impairment.

Copies of the technical report and an executive summary may be obtained from the Rehabilitation Research and Training Center.

Career Development Needs of Blind and Visually Impaired Students and Adults

W.H. Graves, Ed.D.; S. Lyon, M.S.; S. Marmion, Ph.D.; K. Boyet, M.S.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute of Handicapped Research; Mississippi State University*

Purpose—The project addresses the need for research which describes the career development of blind and visually impaired persons, and information on which to base a career-development approach for the delivery of educational and rehabilitative services. The purpose of the study was 1) to identify the career development needs of blind and visually impaired persons across age groups; and 2) to determine which career development needs were perceived as being met by rehabilitative agencies.

Progress—A survey of blind and visually impaired students (grades 3, 6, 9, and 12), teachers (grades K, 3, 6, 9, and 12), parents of blind and visually impaired students, and blind and visually impaired adults was conducted. Two hundred and five students, 127 parents of visually impaired children, and 143 adults answered questionnaires assessing their perceptions of their career development needs and their career services needs; factors were derived which identified the factorial structures of the career development and career services needs of the groups in the sample.

Results—The results indicate that blind and visually impaired students and adults as well as the parents of the blind and visually impaired students do not perceive that their career development needs are being met. Find-

ings of equal importance indicate that the career development process of blind and visually impaired students and adults parallels that of the sighted population. The differences between the two groups that were identified relate to the career service needs of the blind and visually impaired students and adults. The career service needs identified are those services needed to cope with intrinsic and extrinsic factors associated with visual impairments.

The findings suggest that schools and rehabilitation agencies need to examine their career development programs to determine ways in which the programs can be modified to better meet the needs of their students and clients. The findings also suggest that schools and rehabilitation agencies can examine exemplary career development programs for sighted persons and use those programs as a basis for planning career development programs for blind and visually impaired adults and students. The career service needs of blind and visually impaired students and adults can be met within the service delivery context of career development programs which have been shown to be effective in meeting the individual needs of their clientele.

A technical report and an executive summary may be obtained at a nominal fee from the Rehabilitation Research and Training Center on Blindness and Low Vision.

Predicting Work Status Outcomes of Blind/Severely Visually Impaired Clients of Rehabilitation Agencies

J.M. Giesen, Ph.D.; W.H. Graves, Ed.D.; S. Schmitt, Ed.D.; A.M. Lamb, M.Ed.; D. Cook, M.S.; C. Capps, M.S.; K. Boyet, M.S.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute of Handicapped Research; Mississippi State University*

Purpose—The purpose of this study was to assist vocational rehabilitation agencies serving

blind and visually impaired persons in program planning and allocation of agency resources to

increase successful employment closures and reduce the underemployment of blind persons. The study's means are literature review and empirical research. This study sought to identify factors that were associated with four client employment outcomes: competitive employment, sheltered workshop employment, homemaker closures, and nonworking closures. The categories of factors used to predict client employment outcome included rehabilitation process, personal, financial, environmental, occupational, and counselor-related variables.

Progress—Extensive data were abstracted directly from case records of 619 legally blind and totally blind clients, chosen by systematic quota sampling, that were closed as successful (status 26) or unsuccessful (status 28) by rehabilitation agencies in Florida, Kansas, Mississippi, and Ohio. In addition to data from the R-300 form, data were also obtained from case files on disabilities, use of aids, occupational history, expenditures, etc., forming the MSU RRTC Employment Database of over 270 variables.

In this study, stepwise multiple discriminant analysis was used to identify which variables were best able to discriminate among the work status outcome groups.

Results—Using the predictor variables identified by the discriminant analysis, a 68 percent correct classification of work status outcome group was obtained. This was a 270 percent increase over the chance correct classification rate. The 10 best predictors of work status category at closure were age at referral, the skill level (total vocational quotient) of the last IWRP occupational goal, sex, years disabled prior to referral, number of disabilities in addition to blindness, highest grade completed, on the job training, proximity to counselor, wage category at referral, and whether the client received institutional training. Compared to the other three outcome groups, the competitively employed group had more years of education, had higher weekly earnings at referral, had a higher skill level on the first IWRP goal, received vocational school services more often, had more expenditures for prostheses, and received fewer medications and treatments. A technical report with recommendations for policy and practice issues may be obtained at a nominal fee from the Rehabilitation Research and Training Center on Blindness and Low Vision, P. O. Drawer 5365, Mississippi State, MS 39762.

Blind Clients Closed as Homemakers: Employment Outcome Antecedents

J.M. Giesen, Ph.D. and K. Ford, M.S.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute of Handicapped Research; Mississippi State University*

Purpose—The present study was to assist vocational rehabilitation agencies to better serve blind and visually impaired persons in program planning and allocation of agency resources to increase successful employment closures of blind persons by providing an extensive analysis of the homemaker case closure. This study was intended to review relevant literature and provide empirical information on the antecedents of the homemaker case closure, so that client characteristics and rehabilitation process

patterns which lead to homemaker closures can be identified early and appropriate service patterns can be established. Thus, this study seeks to identify the characteristics of clients closed as unsuccessful and to identify factors that differentiate this outcome from other outcome groups. The four client employment outcomes were competitive employment, sheltered workshop employment, homemaker closures, and unemployed closures. The categories of factors used to predict employment outcome of blind

clients included rehabilitation process and personal, financial, environmental, occupational, and counselor-related variables.

This study utilized the 619 blind cases from the MSU RRTC Employment Database. This database was formed in previous research as indicated by the following summary. Extensive data were abstracted directly from case records of 619 legally blind and totally blind clients, chosen by systematic quota sampling, closed as successful (status 26) or unsuccessful (status 28) by rehabilitation agencies in Florida, Kansas, Mississippi, and Ohio. In addition to data from the R-300 form, data were also obtained from case files on disabilities, use of aids, occupational history, expenditures, etc., forming the MSU RRTC Employment Database of over 270 client variables.

This study used stepwise multiple discriminant analysis to identify which variables best discriminate between the homemaker closure group and each of the other three successful employment groups in three separate analyses.

Preliminary Results—Data analysis is in progress and is expected to indicate which vari-

ables will discriminate between the homemaker group and each of the other outcome groups, along with classification accuracy of each of the discriminant functions, and profiles on the differences between the homemaker group and each of the other outcome groups.

The data analysis completed thus far indicates that the discriminant function for the homemaker and unsuccessful groups classified clients significantly better than chance at an overall rate of 78.5 percent. Compared to the unsuccessful group, the homemaker clients were more likely to be female, had a lower skill level of their IWRP occupational goal, were referred when over 16 years of age, were more likely to have received restoration services, lived farther from their VR counselor, were in training for a shorter time, were more likely to receive noninstitutional training, were more likely to be currently married, were less likely to have been referred by an educational institution, received a lesser amount of public assistance at referral, and were less likely to receive maintenance services.

A technical report with recommendations for policy and practice issues is in preparation.

Training Opportunities Profile for Visually Impaired Persons: (TOP-VIP) _____

J.M. Peterson, Ph.D.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute of Handicapped Research; Mississippi State University*

Purpose—The purpose of this project is to develop a series of assessment materials that can be used in vocational evaluation centers to assess the capabilities of blind persons for training in one of the five following job clusters: 1) computer programming; 2) counseling/social work; 3) management; 4) sales; and 5) allied health.

Progress—Technical and professional job clusters were identified which met the conditions of 1) a high number of employed or in-training blind persons; and 2) forecasts indicating that employment possibilities are expected to continue for the foreseeable future.

The information concerning the tasks involved in each of these job clusters and information concerning the characteristics of persons employed to perform these tasks is being collected. Information concerning the job task and manpower requirements is being obtained from literature and interviews with sighted and blind workers, as well as from trainers of blind and sighted persons in the respective job areas.

The information will be used in constructing assessment materials for each job cluster based upon a model of assessment exercise development adapted from business and industry. A national survey of individuals involved in training of such personnel will set criterion-ref-

erenced standards for skill levels.

Preliminary Results—We have published a monograph entitled: *Work Samples and Visually Impaired Persons: A State-of-the-Art Review and Resource Manual* and have developed participant and assessor manuals for all five career areas and a draft Technical Manual. As-

essment materials are now being field-tested in Rehabilitation Centers for the Blind in Mississippi, Virginia, and Oklahoma. Results of the usefulness of materials are positive to date. Finally, a national survey of trainers in all five career clusters has been conducted. Publication of all materials related to this project was completed September 30, 1986.

The Unsuccessfully Closed Blind Client: Employment Outcome Antecedents _____

J.M. Giesen, Ph.D.;

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: National Institute of Handicapped Research; Mississippi State University

Purpose—The present study was made to assist vocational rehabilitation agencies in program planning and allocation of agency resources in order to increase successful employment closures of blind persons, through an extensive analysis of the status of 28 unsuccessful closures. This study was intended to review relevant literature and provide empirical information on the antecedents of the unsuccessful case closure, so that client characteristics and rehabilitation process patterns which lead to unsuccessful closures can be identified early and averted. Thus, this study seeks to identify the characteristics of clients closed as unsuccessful and to identify factors that differentiate this outcome from other outcome groups. (The four client employment outcomes were competitive employment, sheltered workshop employment, homemaker closures, and unemployed closures.) The categories of factors used to predict employment outcome of blind clients included rehabilitation process, personal, financial, environmental, occupational, and counselor-related variables.

Progress—This study utilized the 619 blind cases from the MSU RRTC Employment Database. This database was formed in previous research as indicated by the following summary. Extensive data were abstracted directly from case records of 619 legally blind and totally blind clients (chosen by systematic quota sampling) who had been closed as successful (status

26) or unsuccessful (status 28) by rehabilitation agencies in Florida, Kansas, Mississippi, and Ohio. Finally, in addition to data from the R-300 form, data were also obtained from case files on disabilities of clients, use of aids, occupational history, expenditures, etc., forming the MSU RRTC Employment Database of over 270 variables.

This study used stepwise multiple discriminant analysis to identify which variables were best able to discriminate between the unsuccessful closure group and each of the other three successful employment groups in three separate analyses.

Results—The discriminant analysis between the competitive and unsuccessful groups showed a correct classification of 66.4 percent which was significantly better than chance. Compared to the competitive group, the unsuccessful clients lived closer to their VR counselor, had a lower skill level of their IWRP occupational goal. They were less likely to use optical aids, had lower expenditures for surgery and other physical restoration procedures, and had been out of work over three times longer. They were more likely to have a severe secondary disability, were more likely to be supported by transfer payments at referral, were less likely to have received noninstitutional training, were more likely to have received SSDI during service, were disabled for a shorter period prior to referral, and had more disabil-

ities in addition to blindness.

The discriminant function for the sheltered and unsuccessful groups classified clients significantly better than chance at an overall rate of 83.9 percent. Compared to the sheltered group, the unsuccessful clients were more than two times older at onset of blindness, had much lower expenditure for personal or vocational adjustment training, were more likely to be white than nonwhite, and had an education level almost three grades higher than the sheltered group clients.

The discriminant function for the homemaker and unsuccessful groups classified clients significantly better than chance at an overall rate of 78.5 percent. Compared with the

homemaker group, the unsuccessful clients were more likely to be male, had a higher skill level of their IWRP occupational goal, were referred when over 16 years of age, were less likely to have received restoration services, were in closer proximity to their VR counselor, were in training for a longer time, were less likely to receive noninstitutional training, were less likely to be currently married, were more likely to have been referred by an educational institution, received a greater amount of public assistance at referral, and were more likely to receive maintenance services.

A technical report with recommendations for policy and practice issues is in preparation.

Research into the Development of a Nonisomorphic Codification System for Electrocutaneous Sight Substitution

Stewart Ferguson, Ph.D.; and Sherry Ferguson, Ph.D.

University of Windsor and University of Ottawa, 1965 Fairglens Mews, Blackburn Hamlet, Ottawa K1B 5A5, Canada

Sponsor: N.S.E.R.C. and the National Research Council of Canada

Purpose—The purpose of our work has been to establish the feasibility of a sequential nonisomorphic coding system as an alternative to the isomorphic analogue coding system used by previous researchers in vision substitution work. (The theoretical base for our approach is described in an article by these authors published in the *Journal of Visual Impairment and Blindness*, January 1986.)

Progress—In the initial period of work, the technical staff at N.R.C. designed and built to our specification an electrocutaneous impulse generator, sequential encoder, nonisomorphic transducer, and fixed test pattern modules.

The initial work involved investigating the possibility of a more flexible codification system afforded by the use of a biphasic impulse generator. Many of the shortcomings of the single-phase approach, which were in large part responsible for a shift from the electrocutaneous approach to the vibrotactile approach, seemed likely to be avoided by the biphasic approach, and this proved to be the case.

Our next task was to investigate the possi-

bility of decoding linear relationships through a nonisomorphic transducer pad. Because of the possibility of a more compact transducer afforded by a nonisomorphic approach, the pad was first designed to be worn on the forearm. However, tests confirmed that the abdomen offered a much more sensitive transfer point, as had been found by previous workers.

A series of tests was run to check on the learnability of linear relationships using nonisomorphic transfer. These tests involved repeated recycling of 100 points of location along a line. To speed up the learning time, the sentence was displayed on a line of LEDs. After several hours of training, the subject was able to locate with some accuracy the position along the line indicated by a single point signal. The next series of tests involved the encoding of repeated patterns of interruptions along the line, using fixed pattern modules. Although some level of success was achieved in these test, the subject had difficulty in sustaining the ability to distinguish a set pattern. This we attributed to the masking which took place as a consequence of the physiological accommodation in-

duced by the fixed repetitive input.

Future Plans—At present, we are developing a hand held photoelectric pickup device, in order to introduce a higher level of dynamic input and will use this to explore light patterns in a

way more approximating the natural system. Work on a prototype of the photo-sensor is being carried out at the National Research Council of Canada Medical Engineering section, where we have been granted guest worker privileges.

Microcomputer Magnification for Low-Vision Users

Lawrence H. Boyd, Ph.D.

Berkeley System Design, 1708 Shattuck Avenue, Berkeley, CA 94709

Sponsor: *National Eye Institute*

Purpose—The objective of this project is to develop an aid for partially sighted people that enhances access to mainstream computer technology through the software magnification of computer displays.

InLarge evolved through two generations of prototyping. The first generation was implemented on the Apple Macintosh as a desk accessory which could be called up anytime during the use of major applications. This prototype produced a magnifying glass like window on the screen containing a pixel-magnified view of the area around the cursor. While this prototype demonstrated the feasibility of the software-based approach and its advantages over other approaches, subsequent evaluation with low vision subjects revealed a considerable number of shortcomings. These included flickering effects from rapid movements of the pointing device, the inability to magnify the cursor or pull down menus, unintended concealment of portions of the application display and of the magnified area by application windows, inability to position the magnifying glass through the keyboard, the loss of context and place when scanning text, and difficulty in moving from application to application.

Progress—To remedy these shortcomings, a completely different approach to integrating inLarge was implemented. In effect, the second generation inLarge instructs the operating system to create and maintain a duplicate image of the real display, and to selectively superimpose user selected parts of that image on the real display. This approach to integration

proved to be an extremely effective solution to the problems of the desk accessory approach. Complete independence from other system software with unrestricted control of the appearance of the screen made possible new solutions to the problems of context and loss of place, including a tracking option, and a feature which keeps the position of the cursor in the magnified view consistent with its position on the real screen.

Preliminary Results—Product development was accompanied by basic research into design questions involving screen magnification and human performance. An immediate question for software development was whether the grainy appearance of magnified letters required some kind of cosmetic programming. Results from a controlled experiment assisted by Professor Ian Bailey, School of Optometry, University of California, Berkeley suggested that letter graininess due to magnification does tend to increase scanning time and reading errors. However, the magnitude of these effects does not warrant immediate attention.

Future Plans—InLarge is currently being readied for field testing and distribution to users. This includes the development of appropriate documentation and an easy to use "configuration screen" for tailoring user options to individual needs. The major tasks of subsequent research and development are to extend availability to other machines and operating systems, to supplement magnification with audible cues for very low vision users and to develop specialized

support materials, in the form of large print manuals and audio cassettes which meet the

special needs of low vision users in diverse settings and requirements.

Sensorimotor Aspects of Visual Rehabilitation Using Head-Mounted Magnification Devices

Joseph L. Demer, M.D., Ph.D.; Franklin I. Porter, M.S., O.D.; Herman A. Jenkins, M.D.; Jefim Goldberg, Ph.D.
Cullen Eye Institute and the Clayton Foundation for Research Neurotology Laboratory, Baylor College of Medicine, Houston, TX 77030

Sponsor: *National Eye Institute and the Clayton Foundation for Research*

Purpose—Potentially a great majority of severely visually impaired persons could benefit from spectacle magnification aids such as telescopes or microscopes. But many low vision patients cannot tolerate spectacle magnifiers or use them functionally. We hypothesize that this may be due to inadequate ocular motor stabilization reflexes. Retinal images must not be perturbed by ubiquitous head movements, because retinal image slip of more than a few degrees per second degrades visual acuity. Retinal image stability is normally achieved by the vestibulo-ocular reflex (VOR) in conjunction with visual tracking mechanisms.

The VOR uses head velocity information sensed by the inner ear to reflexively move the eyes to eliminate retinal slip. VOR gain (eye velocity/head velocity) is normally equal to 1.0 during vision, and is about 0.7-0.9 in alert subjects in darkness. The increase in VOR gain produced by vision is the result of visual-vestibular interaction (VVI). When spectacles are worn, the VOR gain required for eliminating retinal image slip must equal the magnification factor of the spectacles. Visual acuity suffers when VOR gain is not appropriate to spectacle magnification. Fortunately, animal experiments have shown that VOR gain, as measured in darkness, undergoes gradual plastic adaptation to ultimately compensate for 2X spectacle magnification. Similar adaptation also occurs in humans, although blurred vision and motion sickness may often occur until adequate adaptation develop.

We hypothesize that inadequate VOR gain plasticity and inadequate visual-vestibular interaction (VVI) are major factors in failure of low vision patients to functionally benefit from

spectacle magnification aids. These factors have been clinically overlooked. We have assembled a team of eye care specialists, vision scientists, biomedical engineers, orientation and mobility specialists, and rehabilitation professionals. We are employing computer assisted electro-oculography during active and passive head movements to accomplish the following:

- 1) Measure VOR gain plasticity and VVI with telescopic spectacles (2X, 4X, 6X, and 8X) in normal and low vision subjects;
- 2) Study subjects' dynamic visual acuity (DVA) which is the acuity achieved during head movement and contrast sensitivity function, while wearing telescopic spectacles;
- 3) Determine clinical magnification efficiency (actual/predicted acuity) of telescopic spectacles;
- 4) Retrospectively determine if plasticity, VVI, DVA, magnification efficiency, and contrast sensitivity are different in low vision patients who ultimately succeed versus those who fail in daily use of head-mounted magnifying aids; and
- 5) Construct and validate a predictive function of success in long-term functional use of head-mounted magnification devices.

Future Plans—Preliminary studies indicate that VOR gain plasticity, VVI, and DVA can be clinically measured in normal and low vision subjects. We are currently testing normal subjects to optimize the testing protocol and accumulate a database for fully sighted persons. Studies of telescopic spectacle magnification efficiency are ongoing. A retrospective study of low vision subjects was begun in late 1986.

Trisensor Rearing with Infant Macaques

David H. Warren, Ph.D.; Edward R. Strelow, Ph.D.; B.J. Sonnier, Ph.D.; Austin H. Riesen, Ph.D.
Department of Psychology, University of California, Riverside, CA 92521

Sponsor: *National Eye Institute*

Purpose—We hypothesize that infant monkeys (*macaca arctoides*), reared from birth without vision but fitted with a sensory substitution device, will acquire functional spatial behavior. The device is an experimental version (Trisensor) of the commercially available Sonicguide™, a sonar-based device which codes distance as pitch, direction as Interaural Device (IAD), and surface quality as timbre. The subject is raised alone in a cage with a cloth mother surrogate and various items of environmental enrichment. Various behavioral tests are made during the rearing period, including motor and locomotor activity, and responsiveness to natural sound cues and to looming stimuli. At three months of age, the animal is sacrificed and the brain is prepared for neuroanatomical analysis of visual, auditory, and motor cortical areas.

This experimental condition is compared with three control conditions: normal colony rearing with vision, cage rearing without vision or Trisensor, and cage rearing without vision

but with a Trisensor delivering signals which are uncorrelated with the animal's activities.

Preliminary Results—Neuroanatomical evidence is not yet available. Behavioral evidence from experimental animals suggests good acquisition of spatial behaviors and normal responsiveness to auditory cues.

Future Plans—The purpose of the research is twofold. First, it is desirable to explore the potential usefulness of sensory substitution devices for blind human neonates, but such work is ethically unacceptable at this time, absent knowledge about any adverse effects that might occur such as interference with the development of selective auditory attention. The animal model is a necessary precursor to such work with human neonates. Second, valuable information will be gained about the neuroanatomical consequences of rearing with such an altered sensory environment.

Sensory Aids and Spatial Training of Blind Children

David H. Warren, Ph.D.; and Edward R. Strelow, Ph.D.
Department of Psychology, University of California, Riverside, CA 92521

Sponsor: *March of Dimes Birth Defects Foundation*

Purpose—We hypothesize 1) that blind children have allocentric spatial concepts of their familiar surroundings (such as their homes) but egocentric concepts of novel settings; 2) that the initially egocentric concepts of novel settings can become allocentric concepts with appropriate experience; and 3) that sensory aids (in this case a modification of the commercially available Sonicguide™) offer a means of enhancing the effectiveness of such experience.

Progress—In the first experiment, 5-to-12-year-olds are tested in their own living rooms. Procedures requiring localization of objects from var-

ious station points allow determination of whether the spatial concept used was allocentric, egocentric, or neither. The same test is used in a similar but unfamiliar environment. The subject also constructs models of the objects localized in these settings.

In the second experiment, the same subjects are exposed to novel arrays of objects in a schoolyard setting. In this phase, a test trial follows each training exposure, so that the egocentricity/allocentricity of the spatial concept can be examined as it develops with experience. This procedure is followed under three conditions of auditory reference information: reduced

ambient auditory information (the subject wears ear occluders), normal ambient auditory information, and auditory reference signal (an audible beacon is mounted at a prominent place in the experimental space). One group performs these tasks while wearing the sensory aid; a second group wears the sensory aid during the training exposures but not during the test trials; a third group does not wear a sensory aid at all.

Future Plans—This project is just beginning, and no results are available at this time. Three important kinds of information will be sought. 1) What differences are there between the spatial concepts for familiar and novel settings? 2) What is the nature of the emerging concept of an initially novel setting as it changes (or so we hypothesize) from egocentric to allocentric? 3) Can a sensory aid play a facilitatory role in acquiring spatial concepts of novel settings?

Rabbit ERG Responses to White-Noise Modulated Stimuli

Arthur Koblasz, Ph.D.

Georgia Institute of Technology, Atlanta, GA 30332

Sponsor: VA Rehabilitation Research and Development Service

Purpose—We are presently studying the electroretinogram (ERG) responses to simultaneous electrical and light stimuli. The refractory periods associated with each response will be indicated by Wiener Cross-kernels, which is a special transfer function estimated by using independent white-noise modulations of the combined stimuli. Our main objectives are as follows: 1) to identify the functional differences ERG responses to white-noise-modulated between electrical and light stimuli; and 2) to develop a white-noise electrical ERG protocol which will be safe for clinical testing of patients with opaque media.

Progress—Thus far we have designed and tested a circuit for controlling the electrical stimulus and for subtracting the stimulus artifact from the ERG response. We have also designed and constructed an apparatus for holding lenses and a small Xenon light source which will be projected into the eye at the same time that the electrical stimulus is applied. The ERG is measured by using a cup electrode, which is a small cup filled with an electrolytic tear solution and containing an annular shaped

Ag/AgCl electrode.

An IBM PC has been assembled and programmed to perform the necessary data acquisition and analyses. Since both the electrical and the light stimuli are white-noise (randomly) modulated, it is difficult to quantify the accuracy and reliability of the hardware and software. We have conceived several protocols for testing the equipment and programs; e.g., the Wiener kernels were calculated when the response was set equal to the stimulus, with a variable delay. We have also tested the electrical stimuli on inanimate objects and found a small error in the current generator circuit, which was corrected. We are presently testing the apparatus and analytical procedures on bullfrogs.

Future Plans—We will next evaluate the proposed clinical test on a population of adult male rabbits. It is unlikely that we will be ready to apply the proposed protocol on humans during the present period of VA support. However, the equipment and analytical methods are being developed with the eventual human study in mind.

The Correlation of Retinal Sources with the Electroretinogram

Kent Davey; Art Koblasz; Bill Nation

Georgia Institute of Technology, Atlanta, GA 30332 and Veterans Administration Medical Center, Decatur, GA 30033

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The research objective is to realize a correlation of the clinical electroretinogram (ERG) with retinal source activity. Specifically, the question being addressed is, "Given a knowledge of surface potential distribution across the cornea, can one infer a commensurate retinal firing sequence, i.e., the spatial distribution of current sources responsible for the electrical potential gradients measurable noninvasively?" Mathematically, if one were given the sources, an exact inference of the fields could be made; the inverse problem, unfortunately, has no unique solution. The solution of that inverse problem is further complicated by the fact that rods are extremely sensitive compared with cones; this means that light directed at a certain spot on the retina (via a slit lamp with lens, or low-intensity laser) also excites numerous peripheral retinal cells due to scattering in the vitreous humor and the high sensitivity of rods to even low-intensity field scattering.

Progress—To obtain a firm grasp on the analytical side of this problem, two computer models have been built to predict the sensitivity

of the corneal potential to various retinal excitation scenarios. The first model is a two-dimensional circuit model of the eye used to solve Laplace's Equation, as various current sources (groups of retinal cells) are fired. The second model builds on the first, solving Laplace's Equation, but accounting for three-dimensional effects by integral theory. Both models indicate that some degree of source localization can be inferred if the scattering is minimal and noise effects are small.

Given that these two problems (noise and scattering) are often quite serious in a typical clinical context, a third scenario has been investigated employing a series of measurements in time rather than a series of spatial measurements (across the cornea). The temporal measurements will be triggered by a set random ring stimuli, each ring corresponding to a separate ring on the retina. The autocorrelation of multiple ERG measurements with the input stimuli may yield an accurate picture of the retinal source impulse response. Experiments are being conducted on frogs to evaluate the viability of this thesis.

Local Authority Social Rehabilitation Services to Visually Handicapped People

Penelope Shore

Royal National Institute for the Blind, 224 Great Portland Street, London W1N 6AA, England

Sponsor: None Listed

Purpose—This study provided a survey of the current Local Authority provision in England and Wales of social rehabilitation services for visually handicapped adults, together with an investigation of the needs and expectations of visually handicapped people in relation to social rehabilitation.

Preliminary Results—The survey of Social Services Department personnel and their clients in a stratified 17 percent sample of Local

Authorities revealed that age and location are the 2 primary factors affecting the delivery of rehabilitation services to newly blind people. The survey demonstrated that the availability of specialist assessment and rehabilitation services was likely to vary significantly not only from one Local Authority to another, but also within individual Local Authority areas. The majority of visually handicapped respondents to the survey (57 percent) had not been offered practical rehabilitation training, and over a

third of those interviewed claimed not to have been given any information about the services and benefits available to them.

Only a small minority (18 percent) had been offered any advice or counselling about their feelings towards loss of sight.

Particularly disturbing was the identification of very low levels of provision for people over the age of 65—less than a third of those in this age group were offered rehabilitative training, compared with 90 percent of the 20-49 year olds interviewed—evidence which suggests that discriminatory attitudes towards age attitudes result in discrimination against elderly visually handicapped people in respect of the rehabilitation services available to them.

The report points to unacceptable delays in the registration procedures which are, in the great majority of cases, the essential preliminaries to the initiation of rehabilitation services. It substantiates existing evidence of wide variation in the numbers and caliber of Social Services Department staff responsible for assessing the needs for visually handicapped people and providing rehabilitation services to them. Among the sample as a whole, there were considerable variations in specialist staffing levels.

Only 21 percent of the Local Authorities surveyed appeared to have reached an acceptable standard of rehabilitation service. Features that were common to these few authorities included clearly defined management structures, the coordinated provision of specialist field-work staff, and the provision of day-centre rehabilitation programs.

Future Plans—Elsewhere, the evidence presented in the report on Local Authorities' future plans suggests that, in areas where provision is already poor, the situation seems likely to deteriorate further. The report also highlights deficiencies in the management of specialist services to the visually handicapped. In many areas there were no clear policies for service delivery, no arrangements for the effective monitoring of rehabilitation services by Social Services senior management, and in many instances no clear line of managerial responsibility from the Director of Social Services to the social worker in the field. The report reveals that the lack of development must be attributed not simply to economic constraint alone, but also to the low priority accorded to the needs of visually handicapped people within Social Services Departments.

Development of a Visual Evaluation and Training Book: The Vet Book

Gregory L. Goodrich, Ph.D.; Olga Overbury, Ph.D.; Edwin Mehr, O.D.; Robert D. Quillman, M.A.
Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304
Sponsor: VA Rehabilitation Research and Development Service

Purpose—The VET Book project seeks to develop a near-vision training manual for use in clinic or home training of persons with functional residual vision. Approximately 2 million individuals in the United States are classified as legally blind. Of these, approximately 80 percent are partially sighted. An additional 2-to-3 million people have vision that can only be corrected to 20/70 or worse. Included in these categories are approximately 265,000 veterans.

The rehabilitation needs of these partially sighted persons include prescription of low vision aids and training in the use of their residual vision. Services to assist these individ-

uals range from optometrists and ophthalmologists to comprehensive rehabilitation centers; however, most are able to offer only two or three appointments. These limited appointments do not provide an opportunity for vision training, which has been shown to be essential in maximizing the individual's ability to overcome a visual handicap. The VET Book project is developing training materials that can be prescribed in the low vision clinic and then used for home training.

Research conducted by the Western Blind Rehabilitation Center and others has shown that training reduces the rate of rejection of

low vision aids, improves near-visual capacity for reading, and improves an individual's ability to travel independently. Such training, though highly effective, has not been routinely available (except in the most comprehensive rehabilitation settings) because it has traditionally required intensive staff contributions of time—typically one-on-one training of 15 to 20 hours over a 3-or-4-week period. Since low vision services are not covered by health insurance plans or Medicare/Medicaid programs, the services have been too expensive for most low vision programs to implement. Comprehensive low vision services including training are largely limited to the Veterans Administration rehabilitation programs, and even in those programs, budget pressures make it desirable to reduce the time needed to complete a rehabilitation program.

The project will also develop training materials that will allow training to be conducted in low vision services that currently cannot afford such programs, and may reduce the cost of programs offering such training.

Progress—Pilot testing of the VET Book has begun at the Western Blind Rehabilitation Center and at the low-vision clinic at the Royal Victoria Hospital, McGill University, Montreal. Research to date has shown that visual perceptual capacity can be improved through the use of home training materials, and that the improvement is equal to (and perhaps better than) that obtained with clinic training.

The VET Book is designed to train either central or peripheral vision, depending upon the patient's visual needs. Four training sections are currently being developed. These are COPY/DRAW, TARGET MATCH, FIGURE-

GROUND, and READING. The first three sections are designed to train perceptual skills and sensory motor skills necessary for a variety of near tasks including scanning/searching text, viewing pictures, etc. The reading section, as the name implies, trains reading skills including the eccentric viewing skills necessary for individuals with central visual-field deficits.

Preliminary Results—Preliminary data indicate that the current VET Book materials are effective and differentiate between partially sighted individuals having the same visual acuity. The data indicate that the materials are effective in terms of individual perceptual function, rather than merely reflecting sensory capacity.

Testing of materials developed for the VET Book continues, and a proposal for funding of the project has been submitted.

Future Plans—Each training section will be divided into three levels of difficulty. The remaining sections of the VET Book will be a section of tests designed to assess an individual's training progress, a section describing visual pathologies which will contain useful information for the patient and his/her family, and normative data useful to the clinician in defining the individual's level of visual functioning.

The VET Book is intended to be contained in a three-ring binder so that the clinician can select only the appropriate materials for the patient and have these materials photocopied for the patient to take home. Thus the VET Book will not have to be purchased for each patient, and the only added training cost will be for photocopying.

QUO VADIS: Voice-Output Questionnaire Administrator

Gregory L. Goodrich, Ph.D. and David L. Jaffe, M.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—There are recurring needs for clinical programs to accomplish the following: 1) provide follow-up services to veterans; 2) develop

quality-control procedures; 3) assess the impact of the clinical program on the veteran; and 4) survey the needs of veterans for various clinical

services.

Clinical programs in blind rehabilitation centers face unique problems in responding to these needs, because commonly used techniques such as printed questionnaires and surveys are not appropriate for a visually impaired population. Alternative techniques such as telephone interviews are very time-consuming, and are also vulnerable to human bias.

It is proposed that a telephone-accessible, computer-based, interactive speech synthesizer system can be developed to greatly reduce the cost of gathering needed information from visually impaired veterans, while increasing the amount and quality of data collected. The system, currently bearing the name "Quo Vadis," would also be capable of performing relevant data analysis and could be used to facilitate communication of the results to appropriate persons.

The proposed system calls for an IBM PCXT compatible computer with printer, a DECtalk speech synthesizer, and appropriate software. The DECtalk unit has been chosen because it is readily understood even by those who have no computer experience.

Prior to administration of a questionnaire, a staff member would telephone each veteran, explain the purpose of the call and the nature of the questionnaire, and explain that it would be administered by a computer. The interviewer would also tell the veteran to respond to each verbally presented question by pressing the appropriate key on his/her Touch Tone™ telephone keypad. The veteran would then be

given an opportunity to ask questions or to decline the automated questionnaire. If the veteran declined, the questionnaire could be administered by the interviewer.

It is estimated that the initial "human-to-human" telephone call will last 10 minutes and the computerized administration of the questionnaire would require an additional 20 to 25 minutes, so that the entire "interview" would be about 40 percent shorter than if entirely done by a staff member.

Progress—A voice-output "information kiosk" has been developed. It uses the telephone system and a centrally located microcomputer and DECtalk speech synthesizer to disseminate RR&D project summaries. In operation, when a user calls the computer, he or she is greeted by the artificial DECtalk voice. The user is then prompted to press buttons on his/her Touch-Tone keypad to choose the project information to be retrieved from the computer and "spoken."

Future Plans—The pending pilot study will be based upon the above work, and is expected to result in the creation, testing, and evaluation of special-purpose software for administering questionnaires, and to provide for its integration with commercial computer hardware. A goal of this project is to construct a complete system with which nontechnical staff personnel can easily create questionnaires, information dissemination systems, interviews and other interface systems.

The Effectiveness of a Blind Rehabilitation Program

R. Lambert, Jr., M.D.; S. Becker, Ph.D.; B. Wright, Ph.D.; S. Courington, Ph.D., L. Ludlow, Ph.D., E.M. Schulz, M.S.; D. Burnet, B.A.

Veterans Administration Medical Center, Hines, IL 60141

Sponsor: VA Rehabilitation Research and Development Service

Purpose—To assess the effectiveness of the Blind Rehabilitation Center, it was necessary to develop instruments to measure quality of life or life state: i.e., attitudes toward self and blindness, independence in activities and travel, and psychological state. We validated scales to

measure these variables with data collected in a series of pilot tests. (The way in which these scales were to be used in the evaluation study and the way in which they fit into a general model of the rehabilitation process were described in a previous report.)

Progress— Our evaluation model required that we measure a patient's life state before he or she entered the rehabilitation program, shortly after completing the program, and again 6 to 9 months later. Since the report mentioned above, 245 patients have completed initial interviews, 190 patients have completed second interviews, and 143 patients have completed third interviews. We are continuing the data collection, focusing in three areas: 1) continued analysis of the measuring instruments' validity; 2) preparation of the program and data for future analysis; and 3) integration of the data into a larger database management system.

We have constructed all of our measuring and survey instruments; most have been thoroughly tested, analyzed, and reported in the literature. In the past year, we compared the method of scaling used in developing the measures with factor analytic techniques. We found that Rasch Scaling techniques gave stable, unidimensional scales, while factor analysis gave scales of indeterminate strength and fluctuated from group to group, and therefore was too unreliable for research purposes.

We revised the Attitude Toward Blindness

Scale to make it applicable to wheelchair-bound individuals. We then completed the analysis of the validity of the activity and travel measure. While we collected data primarily to validate the activity and travel measure, our additional analyses made it possible to develop a needs assessment of the rehabilitated blind veteran.

We also have constructed two information systems for the blind rehabilitation evaluation project. Through these systems a large amount of data is collected from each patient in multiple interviews, including a demographic file, a medical history and physical exam, an ophthalmologic exam, and five separate survey instruments, each of which is administered three times. The information system to manage the flow of work and data is an easily mastered, user-friendly system that can be adapted to many types of project management. The patient information resides in a database management system which is an industry standard DBMS with full security protection and privacy locks. It has the capacity to be used by many different programs and can easily be adapted to other research projects.

Predicting the Visual Abilities of Partially Sighted Persons

John Trimble, Ph.D.

Veterans Administration Medical Center, Hines IL 60141

Sponsor: VA Rehabilitation Research and Development Service

Purpose—More than three-fourths of America's legally blind population may have useful residual vision. Many of these people could benefit from visual aids, but either they have not had them prescribed or they are not using the aids they have received. Accordingly, they must rely upon sighted people to help them perform many of the activities of daily living.

One explanation for this problem has been that the traditional tests of visual function used to prescribe low-vision aids do not tell us about an individual's ability to perform everyday tasks. This information is essential for prescribing aids that allow an individual to make the most of his or her remaining vision.

Progress—The goal of our study is to apply new measures of visual function to give us an understanding of the visual environment of partially sighted persons. The measure we are concentrating on is called the "contrast sensitivity function" or CSF, which gives us an indication of how well people see details of different sizes. We are measuring the contrast sensitivity function of partially sighted persons and then using these functions to process images by computer.

Theoretically, the images processed by computer will show us how the environment appears to partially sighted persons. If this is true, then we will perform additional studies in an effort to determine which aspect of the con-

trast sensitivity function is most closely correlated with the person's ability to perform certain tasks. In the first stages of the study, we will examine simple tasks such as recognizing letters, shapes, and faces. Later, we will study more complex tasks such as those encountered

in daily living. If our study is successful, we will gain a better understanding of the implications of severe visual impairment, and we will also develop techniques that may be useful in reducing the handicaps associated with it.

Computer Vision for the Blind

B.K.P. Horn and E.J. Weldon, Jr.

Department of Electrical Engineering, University of Hawaii at Manoa, Honolulu, HI 96822

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Our work has concentrated on low-level vision problems. Specifically, we have addressed the problem of how a monocular observer moving in a fixed environment can determine its motion and the depth of the world points in its field of view. This problem is important for a blind-assist prosthesis; its solution will simplify the mid- and high-level computational tasks which must be performed by such a device.

Progress—We have developed robust methods for recovering the motion of an observer in a static environment in the case of pure rotation, pure translation and arbitrary motion when the rotation is known. Some of these methods are based on the minimization of the difference between the observed time derivative of brightness and that predicted from the spatial brightness gradient, given the estimated motion. We

minimize the square of the integral of this difference taken over the image region of interest. Other methods exploit the fact that surfaces have to be in front of the observer in order to be seen.

We do not establish point correspondences, nor do we estimate the optical flow. We do not use higher derivatives of the image brightness, and we do not assume an analytic form for the surface.

We show that the field of view should be large to accurately recover the components of motion in the direction towards the image region. We also demonstrate the importance of points where the time derivative of brightness is small and discuss difficulties resulting from very large depth ranges. We emphasize the need for adequate filtering of the image data before sampling to avoid aliasing, both in the spatial and temporal dimensions.

Pilot Studies in the Area of Sensory Substitution

Jacqueline Wertsch, M.D.; Paul Bach-y-Rita, M.D.; Clement J. Zablocki

Veterans Administration Medical Center Rehabilitation Medicine Service, 5000 West National Avenue, Milwaukee, WI 53295

Sponsor—VA Rehabilitation Research and Development Service

Purpose—Following the loss of vision, rehabilitation engineering approaches have been shown to be effective in providing substitute sensory information. An example of this is the ability of the congenitally blind person to perceive visual information picked up by a TV camera and provided in a tactile form onto his back. The purpose of these pilot studies was to explore the

feasibility of expanding this sensory substitution concept and technology to disabilities involving tactile deficits.

Progress—The disabilities involving tactile deficits which were explored were in four main groupings: 1) the insensate diabetic foot; 2) the blind diabetic with sensory deficits in the hands

due to peripheral neuropathy; 3) the spinal cord injured individual with risk of developing pressure sores because of inadequate sensation; and 4) the insensate hand in the peripheral nerve injured individual and in the spinal cord injured individual.

A Program Planning Conference was held in Milwaukee, Wisconsin to evaluate these concepts. The physiology of the sensory system and the pathophysiology of the individual disabilities were discussed in detail by participants representing multiple disciplines in such fields as rehabilitation medicine, engineering, computer systems analysis.

Based on advice from the program planning conference, the initial work focused on the insensate hand and foot. Commercially avail-

able pressure transducers were evaluated and a suitable transducer was identified and tested. For the insensate foot pilot work a method of encapsulating the transducers into the insoles by using silicone rubber was tested. Signal analysis and signal display systems were formulated. An electrotactile display system became commercially available and was found to be appropriate for use as an initial display system.

Future Plans—The initial work suggests that sensory substitution is a viable technological development for disabilities involving tactile deficits. Further investigation will focus on development of a sensory substitution system for the insensate foot.

2. Mobility Aids

Measuring the Mobility of Blind Travelers

Rebecca Hollyfield, Ph.D.

Veterans Administration Medical Center, Hines, IL 60141

Sponsor: VA Rehabilitation Research and Development Service

Purpose—One must be able to measure the effect of a blind mobility training program on the blind traveler to adequately evaluate its effectiveness. Two different approaches have been used previously to measure the blind traveler's mobility: a measurement of the travel skills of the traveler, and a determination of the person's amount and type of travel. Recent improvements in these measures now make it feasible to study programmatic effectiveness. One of these improvements is the use of a portable, ultrasonically-based, gait-measuring system. This system measures the traveler's step length, time, and cadence while walking. The other improvement involves the use of a more psychometrically-valid questionnaire for assessing the travel behavior of the blind person.

Our study measures the travel skills and travel behavior of two groups of veterans: low-

vision travelers and blind travelers. We are measuring the travel skills with the inter-ankle-distance measuring system and the travel behavior with the Travel Inventory.

Progress—We are measuring the skills and behavior on four occasions; twice prior to training and twice after.

Future Plans—Once we have gathered the measurement data, we will assess the relationship between these two sets of measures and across the four measurement points. We hypothesize that the level of travel behavior at the fourth measurement will not be fully explicable in terms of the acquired travel skills, because there are other factors in addition to travel skill that affect actual travel behavior.

Clinical Application Study of Training Techniques and Devices for the Blind

William R. De l'Aune, Ph.D., and Duane Geruschat, Ph.D.

Eastern Blind Rehabilitation Center, Veterans Administration Medical Center, West Haven CT 06516

Sponsor: VA Rehabilitation Research and Development Service

Purpose—At the present time there is no universally accepted evaluation procedure in the performance of orientation and mobility (O&M) by the blind and partially sighted. This has serious implications in terms of program and device evaluation as well as for documentation of patient progress. To address some of these concerns, the National Institute of Handicapped Research (NIHR) has supported the development of an O&M evaluation protocol at the Pennsylvania College of Optometry (PCO) R&D Center. The investigators in this project, through cooperative efforts between the Veterans Administration's Eastern Blind Rehabilitation Center (EBRC) and PCO, have been actively involved with the development and refinement of this protocol.

Progress—While the population studied at PCO is large and potentially representative of the visually impaired population of the United States, there are basic differences related to gender, visual history and secondary conditions between this population and that served by the VA. The current project seeks to adapt and extend the O&M evaluatory protocol to accommodate these perceived differences, to integrate and increase the number of subjects' scores contained in a cumulative O&M research database and to establish the reliability and validity of the measures when used with the veteran population.

All initially stated objectives of this project have been completed within the proposed timelines. A total of 36 subjects have been tested with 19 being seen for both pre-testing and post-testing. All clients of the blind center have been accounted for with only those who were physically incapable of completing the mobility routes being exempted. The entire mobility staff has participated in the development of the test routes and in the data collection.

Results—Inter-observer reliability was found to be satisfactory. The validity of the protocol was demonstrated by two methods. In the first, the assumption of skill improvement after the completion of the residential training program was verified by a significant increase in the pre-post test scores of the subjects ($t(18) = -3.29$, $p < .001$). In the second, the entire O&M staff was required to independently rank the veterans in terms of mobility performance. The mean staff ranking was correlated with the test scores of the clients for an $r(17) = .627$, $p < .001$. This high degree of agreement with clinical judgment demonstrates the utility of the measure for objective client performance assessment and documents the efficacy of using clinical staff to quantify functional performance.

Since most of the veterans had some remaining vision, the mobility test route did not present a consistent challenge to their travel abilities. It was possible for a subject to walk a number of blocks before experiencing mobility problems. It appears that the mobility problems tended to cluster around high demand situations such as street crossings and high pedestrian and obstacle volume. In all other situations, the subjects performed with a high rate of travel efficiency and safety. Due to the time involved to walk the route and the physical limitations of the primarily elderly and sedentary subjects, it was not possible to extend the route to generate higher performance scores.

Future Plans—Because of ceiling and floor effects of the present methodology, additional research is being undertaken to develop more highly refined measures of O&M performance, emphasizing metrics concerned with the mental effort involved with travel situations. Secondary task methodologies will be utilized to obtain data concerning mental effort associated with O&M tasks of varying difficulty levels, before, during, and after training.

SONA-ECS

Gary W. Kelly; David A. Ross; Richard M. Bass; Theresa M. Ackerman; Jeffrey L. Smith

Atlanta Veterans Administration Medical Center, Rehabilitation Research and Development Unit, Atlanta, GA 30033

Sponsor: VA Core Funding

Purpose—The SONA-ECS (Sonic Orientation and Navigational Aid - Environmental Control System) is a digital, radiofrequency transmitter-receiver system that has applications for persons with manual impairments as a decentralized environmental control system.

Progress—SONA-ECS has proved to be highly reliable and to function well technically. SONA-ECS has had approximately 8000 hours of field testing to date, both in a work environment and in a veteran's home. It is also being used to operate a van lift system where it is necessary to open the side door and operate the wheelchair lift control and interior lights in a van.

The SONA-ECS transmitter and receiver are microprocessor-based. The transmitter has been interfaced through RS-232C to a microcomputer and is operated under program control. The receiver also has implemented RS-232C serial communication. In addition to simplifying the hardware, the current design enhances the system's capabilities, as many modi-

fications and improvements can be implemented through software. The system is capable of being used with a broad range of input/output devices. In a special application, the transmitter is being controlled through joystick input from an intelligent microprocessor wheelchair controller. The digital coding of the radio signal can be expanded so that transmitters for different uses or disabilities will send a different generic use code in addition to the device code.

Future Plans—The Atlanta Veterans Administration Medical Center intends to continue development and evaluation of this system. The project will focus on enhancing the performance and capabilities of the system through the application of microprocessor technology and examination of new areas of application.

The final result of this project is intended to be the development of products which are low cost and easily manufactured. Discussions are currently being held with potential manufacturers to produce the system.

SONA-Sonic Orientation and Navigational Aid

Gary W. Kelly; Lisa W. McNeal; Theresa M. Ackerman

Atlanta Veterans Administration Medical Center, Rehabilitation Research and Development Unit, Atlanta, GA 30033

Sponsor: VA Core Funding

Purpose—The Sonic Orientation and Navigational Aid (SONA) is designed to alleviate the problem of independent mobility for a visually impaired person by providing auditory orientation cues. The SONA consists of a digital, radiofrequency transmitter-receiver system. The microprocessor-based transmitter carried by the visually impaired traveler signals receivers placed over the desired or emergency locations. When the receiver detects its coded signal (which is different for each location), it emits a series of pleasing musical tones called Musical Language.

Progress—The human factors aspects of SONA have been of primary importance throughout its development. A pilot study of the prototype SONA system was completed at the Atlanta Veterans Administration Medical Center with subjects representing a wide range of visual impairments from low vision to total blindness. Twenty-three out of 24 volunteer subjects who evaluated the prototype system expressed much enthusiasm about its potential, although opinions were mixed as to whether the system would be most useful in a familiar or unfamiliar environment (indicating that such a judg-

ment depends upon individual user differences). The measures used in the study were purely subjective, and the number of subjects tested was too small for the conclusions drawn to be considered universal; however, their high praise for the system in general has been encouraging and their suggestions for design improvements have been helpful.

Some examples of the suggestions to be incorporated include making the transmitter smaller and easier to carry, and mounting the receivers at consistent heights. Most of the persons who evaluated the SONA system believed it would be very useful in mobility training.

3. Reading Aids

Tactile Graphic Braille Display

Gregory L. Goodrich, Ph.D., and David L. Jaffee, M.S.

Rehabilitation Research and Development Center Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Computer access is a necessary prerequisite for many vocational and educational tasks today, and this trend is likely to increase over the next decade. It is estimated that by the year 1990, as many as 90 percent of all jobs will involve some interaction with a computer. A major component of the expanded role of computers will be the increased use of graphics to convey information (e.g., graphs, pie charts, or icons). These displays pose a potential problem for visually impaired individuals, since there is currently no way to present graphic computer information to them.

The goal of this project is to assemble the necessary technology to construct an inexpensive tactile graphic display, in an attempt to significantly improve the educational and vocational opportunities for thousands of blind and visually impaired people.

The most common means used by visually impaired people to access computers are synthetic voice, single-line refreshable braille displays, hard-copy braille printers, optical low-

Future Plans—Based on further funding, development and evaluation of the SONA system will be continued to enhance the performance and capabilities through the application of microprocessor technology to provide an optimal orientation aid for the visually impaired person. The final result of this research is intended to be the development of an orientation aid which is low cost and easily manufactured. Such a system could be implemented on a national basis using standard coding systems which would be determined through human factors testing.

vision aids, and large-print computers. Although each provides some measure of computer access, all have shortcomings, either in function or in cost, that render them unlikely to solve the basic problem.

The project investigators propose that an electromechanical device can be developed that would display tactile braille, letter outlines, and graphics. Such a display, consisting of a matrix of plastic pins that could be selectively raised or lowered under computer control, would be connected to a standard computer to serve as an output device. It would be a functional substitute for the CRT display system used by sighted computer users.

Progress—The American Foundation for the Blind (AFB) has designed a prototype graphic braille display mechanism which is thought to be suitable for presenting graphic and alphanumeric information. The current project will facilitate continued work on that display, the development of companion software, and evalua-

tions of the display in both laboratory and field testing situations.

Software development, being accomplished at the Rehabilitation R&D Center, focusses on providing a transparent interface to commonly available computers such as Apple and IBM product lines. The research program calls for combining the AFB hardware and VA software with concurrent evaluation, so that the design process can immediately benefit from information obtained in the evaluation process.

The computer interface hardware has been procured and some initial programming has been accomplished. Continued development of the prototype mechanical braille display mechanism is under way.

Future Plans—Arrival of the first working units from the AFB is expected in early 1986. At that time, an additional effort will be re-

quired to mate the electro-mechanical mechanism to a standard computer. Evaluation of the completed system will begin at that time.

The evaluation process will be facilitated by the initial construction of three prototype displays, to allow two displays to be used in field and laboratory testing and the remaining prototype to be used for hardware refinement. The plan calls for the three units to be rotated from the AFB to the Western Blind Rehabilitation Center, so that advances in hardware may be immediately incorporated into the evaluation process without the loss of time typically encountered when a solitary prototype is returned for repair or modification.

Upon completion of the project, it is expected that the display, with application software, will have been developed and tested to the point where it can be turned over to a manufacturer for production and distribution.

Establishing Design/Operational Features for Portable Blind Reading Aids

Richard D. Steele, Ph.D., and Gregory Goodrich

Rehabilitation Research and Development Center Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—There is a need for a practical, portable, voice-output reading aid for the blind. Approximately 500,000 Americans (including 50,000 veterans) are totally blind, and another 1.5 million Americans (including 200,000 veterans) are legally blind. Most of these people have no means of unassisted access to inkprint materials, and would benefit personally or professionally from a useful, inexpensive voice-output reading aid. Existing reading aids have achieved only very limited distribution and use, due in part to their failure to address users' comprehensive needs.

This work seeks up-to-date and detailed specification of user needs experimental clinical findings on how best to address them. It utilizes the Computer-based Adaptable Reading Aid (CARA) recently developed at the Rehabilitation R&D Center. The project also utilizes the strengths of two complementary centers—the Veterans Administration Western Blind Rehabilitation Center (WBRC) and the Palo Alto

RR&D Center.

Progress—The RR&D Center has developed the Computer-based Adaptable Reading Aid (CARA) prototype. Utilizing what was learned from the experimental device developed by Telemetry Systems, Inc., in 1980, which combined hand scanning with voice input, the prototype incorporated an easier user access and an expanded reading capability.

The work is organized around three approaches, which are to be addressed sequentially. They are a needs assessment of visually impaired people and blind rehabilitation workers, a critical survey of current commercial reading devices with optical character recognition (OCR), and simulation studies, conducted by a joint clinical-research team and using the flexible CARA prototype. This device is highly flexible in that it allows easy access for device modifications during simulation studies.

The CARA prototype has fully operational

interfaces to the Optacon (a low vision tactile-output device) and the Stereotoner (a device that generates tones that are a function of the shape of a character). Two generations of controller boards for acquiring images of scanned characters are in use.

A first-generation hand-scanning camera has been completed, and a first iteration of front-end image processing and OCR software has been completed.

Current efforts are concentrating on the design of the questionnaires and surveys, and on the functional and logistical aspects of the simulations.

Future Plans—Further work will focuss on the design of a low-cost tactile tracking aid and page scanner for the hand camera, and an audio tracking aid.

Facilitating the Use of Tape Recorded Text by Students with a Visual Handicap _____

A.J. Parkin, Ph.D., and F.K. Aldrich, B.Sc.

Laboratory of Experimental Psychology, University of Sussex, Brighton BN1 9QG, United Kingdom

Sponsor: Royal National Institute for the Blind

Purpose—Visually handicapped college students are dependent on tape recordings for access to academic texts. Phase I of this project has outlined the problems encountered by these students. Phase II is now exploring ways of alleviating their difficulties.

Progress—Phase I: Questionnaire surveys have been conducted to investigate the study methods of visually handicapped students ($N = 70$) and the recording practice and communication

difficulties of volunteer narrators ($N = 50$). Phase II: Experiments are now underway to assess the effectiveness of variable speed and pitch-control devices; tactile line graphs (produced on capsule paper) as a supplement to tape recordings; and restructuring text to be recorded. A 6-letter code to identify recorded books to their users is also being evaluated.

Future Plans—Phase II was concluded in late 1986. A project report will be available in 1987.

Tactile Paper for Visually Handicapped _____

D. Reginald Traylor and Anita M. Corso

Traylor Products & Services, San Antonio, TX 78217

Sponsor: National Institutes of Health; National Eye Institute

Purpose—The purpose of this project was to determine the feasibility of developing a paper containing encapsulated particles which, upon stimulation activated by heat, pressure, light, chemicals or other means via an "imaging pen," would produce an immediate raised, colored, impression along the line of the pen. Upon deformation, it should serve as a master for the Thermoform process. Thermoform is a heat vacuum process that "copies" in three-dimensional form.

Progress—Research was directed toward the current state of the art in encapsulation tech-

nology and after an extensive search of literature, scientific and industrial sources, a source was identified. The initial prototype effort was performed within the established constraints related to safety, total systems cost, and minimal hardware. Two thermally activateable coatings were developed for the paper. One is a water-based coating containing microcapsules of a dye precursor dissolved in oil; a solid acid is suspended in the coating, the reaction of the dye precursor with the acid produces color (this technology is similar to that used in carbonless paper and thermal print paper). The second is a solvent-based coating containing suspended par-

ticles of a thermally activated blowing agent. The binder for this coating is composed of a specific mixture of polymeric and monomeric materials that initially behave as a thermoplastic mass. The application of heat swells this mass through the decomposition of the blowing agent and simultaneously converts the binder into a thermoset mass.

Of the two identifiable technologies considered for the pen, acid ink or a thermal element, the thermal approach was chosen because of existing technology. (The acid approach imposed a danger of not allowing expanding gas to escape.) Keeping in mind the cost constraint on the hardware, a prototype was fabricated from a pencil soldering iron using a standard light-dimmer to lower the soldering iron tip temperature from 800 degrees Fahrenheit to 400 degrees Fahrenheit. Feasibility was thus established when raised and colored images could be obtained using the coatings and pen.

Future Plans—Field test evaluations will be made to research materials, stimulating technologies, color, height and width of lines, and other properties that are necessary to design and produce a quality product. Paper texture

and color contrast will be emphasized. The pen must be lightweight, portable and battery operated. Above all, both paper and pen must be safe, cost efficient, and easy to manufacture. All feedback from the field test evaluators will be analyzed and incorporated into the continuing production until satisfactory results are gained.

Development of the tactile paper and pen is directed toward all ages of the visually handicapped population. The color contrast as well as the tactile reinforcement will benefit the low vision persons; the tactile impression will benefit the blind. Primary markets to be satisfied are educational facilities, institutions serving the blind, employers, state and VA agencies. Applications in school settings include handwriting skills, graphic displays, mapping, and mobility aids, as well as flow charting for computer programmers and as a communication tool in the employment setting. Commercialization of the paper for use in computer generated graphics and illustrations for books for the blind as well as nonhandicapped, particularly kindergarten through second grade, is anticipated.

Enhancing the Reading Skills of Low Vision Individuals with Macular Loss

Gale Watson; John Baldasare; Steven Whittaker; and William De l'Aune
Pennsylvania College of Optometry, Philadelphia, PA 19141

Sponsor: National Institute of Handicapped Research, Rehabilitation Research and Demonstration

Purpose—This overall project is an applied research effort designed to quantify measures of visual and reading skills and to develop computerized training protocols and software that assist low vision instructors in the vision rehabilitation of the target population. The present report represents the work done during the second year of this 3-year study.

Progress—*Part I.* Development of Measures of Visual and Reading Skills: The Pepper Visual Skills for Reading Test (VSRT) is an instrument designed to quickly assess the visual skills required for reading. Developed and described in a previous project (NIHR, 1983), it is being

refined and revised in the course of the current study.

Reliability. Reliability of the various scoring protocols for the test was evaluated in the first year of the project. A sample of fifty macular degeneration patients were recruited from the William Feinbloom Low Vision Rehabilitation Center. All patients had a history of efficient reading before the onset of their visual pathology and indicated a desire to regain reading skills as part of the rehabilitation process.

Inter-observer reliability of the VSRT has been assessed on a subset of twenty patients sampled from the original group of fifty.

An analysis of the test data indicated that

subjects either read inaccurately and slowly, slowly but with accuracy, or with both accuracy and speed. Categorization of the low vision reader into one of these three categories has definite rehabilitation implications.

Decoding Skills as Related to Reading Comprehension. The evaluation of the hypothesis that attainment of decoding skills, as measured by the Pepper VSRT, allows subjects with macular loss to attain a reading comprehension level commensurate with the level prior to macular loss is being undertaken. In addition, a study of age-matched controls, not manifesting conditions of maculopathy, compared to macular degeneration patients and those with intact central fields is under way, also using Gray Oral Reading Test and the VSRT.

Field Testing of the Pepper VSRT. To date, we have data from Carolina Eye Associates, Southeastern Blind Rehabilitation Center, the Senior Blind Program at the Michigan Commission for the Blind, and the Low Vision Clinic at the University of Wisconsin, Department of Ophthalmology. All four sites administered the test before and after the low vision examination and once after receiving a low vision aid and practice in its use. The results indicate performance on the Pepper Test increased across the three administrations of the test.

Part II. Expert System for Training Eccen-

tric Viewing and Reading: Experts in vision rehabilitation experienced in eccentric viewing and reading training were surveyed as to which methods of assessment and training were commonly used. The results of this national survey of 80 clinics were analyzed and interpreted by the grant staff and put into the framework of a basic rule base. A number of modules required for the expert system (inference engines, data structures, operator interfaces, etc.) were programmed and are currently being evaluated. The VSRT, which is used as an analytical tool by the system, has been emphasized. A module to score, report, and store data from this test has been designed. The test database has been interfaced with the large research database of client intake, optometric, and functional information already in use at the WFVRC. This database is used both as a source of client specific information for the expert system and as a mechanism for establishment of baseline data measurements on selected characteristics of eccentric viewing.

Future Plans—After a model or several models of training possibilities are finalized, coding of variants of the commercial programs or original programs, specifically designed for reading problems of individuals with maculopathy, will be initiated.

Human Factors Considerations in the Design of Large Print Visual Display Units _____

Gary Kelly; David Ross; Lisa McNeal

Atlanta Veterans Administration Medical Center, Rehabilitation Research and Development Center, Atlanta, GA 30033

Sponsor: VA Core Funding

Purpose—This research project began in January 1986. Its primary objective is the determination of optimal readability in large-print visual display units (VDUs). Large-print displays (LPDs) are becoming prevalent and have many problems beyond those already encountered in VDUs for persons with normal vision. The present human factors study will examine font or character set, color, inverse versus normal print, spacing between lines/characters, and problems of control in VDUs. Persons with a wide range of visual impairments will be

tested on a software system developed at the Atlanta VA Medical Center to determine these factors.

Progress—Previous work by the authors indicated the need for improved controls for the manipulation of text on VDUs designed for display of large print, such as large-print computer systems. The authors indicated that task dependency may be a factor on the format and control requirements.

To date, work has centered around obtain-

ing essential equipment for the research and establishing the specific protocol for testing. This process is now complete; and the software is being written for the Apple IIe computer for control testing and for the Hewlett Packard 310 for the testing of color, font, and spacing considerations of the display. A closed-circuit television system has been acquired for initial assessment of minimum and optimal print size.

Future Plans—Persons with visual impairments will be selected for testing on the newly developed systems. Selection to obtain an adequate sample will rely on the expert advice of physicians and a local low vision clinic. Pilot

tests will begin with the selection of appropriate fonts for testing, followed by two phases of testing. Phase one will establish reading comprehension scores and words-per-minute as a baseline, and will test the effectiveness of various control types. Mouse, joystick, track ball, and touch pad controls are being tested. Phase two will test readability of fonts, sizes, spacing, color effects, etc. Another reading comprehension test and words per minutes will also be assessed, using the optimal large-print display, to determine if the visually impaired person improves in his reading. This testing will be followed by statistical analysis and reporting of the project results.

B. Deafness and Hearing Impairment

Development of a Digital Hearing Aid and Fitting Procedure

A. Maynard Engelbretson, D.Sc.; Robert E. Morley, Jr., D.Sc.; Gerald R. Popelka, Ph.D.; Bridget Mancano, M.A.; Arnold F. Heidbreder, B.S.E.E.; Michael P. O'Connell, B.S.E.E.; George L. Engel, M.S.E.E.

Central Institute for the Deaf, St. Louis, MO 63110; Department of Electrical Engineering, Washington University, St. Louis, MO 63130; Veterans Administration Medical Center, Temple, TX 76501

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to develop a digital hearing aid and a companion fitting procedure that will improve the precision, flexibility of fit, and utility of hearing aids. Towards this goal, special laboratory-based systems have been assembled to evaluate the overall concept and to develop design specifications for an ear-level digital aid. These systems include a digital hearing aid breadboard (DHAB) and a computer-based audiometer system. The DHAB operates in real time and is better than most analog systems including hearing aids. The DHAB is well suited for parametric laboratory studies of digital processing algorithms intended for hearing aid applications.

Progress—Two major accomplishments have taken place this third year of the project. They are: 1) the fabrication of a wearable version of the digital hearing aid (WDHA) and 2) completion of a preliminary design of a low-power digi-

tal signal processor (DSP) that is suitable for use in an ear-level hearing aid. Each is described below.

Four Wearable Digital Hearing Aid units have been fabricated for clinical field studies. The wearable unit fits in a case 5.5 inches long, 3.5 inches wide, and 1.2 inches thick. The system is comprised of two circuit boards of conventional parts, one which contains the DSP and supporting digital circuitry, and a second which contains analog signal conditioning circuitry, multiplexing circuitry, and a codec chip. The analog circuitry is connected via a flexible cable to an ear module containing an input microphone, probe microphone, and receiver. The battery for the system fits in the body-worn case and provides sufficient power for a continuous period of 10 hours.

The processor circuit board contains a Fujitsu MB8764 DSP, five Hitachi 6116 random access memory (RAM) chips for program in-

structions and data, and circuitry for switching to standby power in the event that the primary battery becomes discharged or is removed. The DSP is well suited for processing audio signals and was chosen for the WDHA because of its low power consumption.

Since the computer-based audiometer controls the parameters of the hearing aid during testing of the patient, a serial interface is included in the WDHA. To minimize power consumption and complexity, a simple shift register was used. The control and clock signals for serial communication are controlled by the audiometer, and the communication protocol is purposely simple. Hearing aid parameters and sound pressure measurements of the probe microphone are transmitted between the hearing aid and audiometer during testing and fitting of the patient.

The DSP program resides in RAM and consists of eight finite-impulse-response (FIR) filters arranged in four channels. Each channel consists of a bandpass filter, limiter, and bandpass filter. The filter-limiter-filter structure allows for the maximum output and gain to be separately controlled within each of four channels to match the patient's discomfort threshold and hearing threshold, respectively. The filters reduce distortion products of the limiting process to ensure that they fall below the masked threshold of the ear.

Although the WDHA is not suitable for commercialization because of its size and power consumption, it has the potential for improving our understanding of issues involving digital signal processing with regard to hearing aids. And, although it is possible to simulate natural conditions of signal and noise in the laboratory, additional important insight can be gained by wearing a device in natural surroundings.

Low Power VLSI Design. An important factor in achieving a practical ear-level digital hearing aid is overall power consumption. Conventional hearing aids typically consume less than one milliwatt of power at a nominal voltage of 1.5 volts. A suitable digital processing structure that operates within these limitations is a logarithmic multiplier accumulator (LMA)

circuit element arranged in the form of a systolic array. A preliminary design of this element has been completed and submitted for fabrication.

At present, low-power designs are best implemented in CMOS (Complementary Metal Oxide Semiconductor) technology. The major source of power consumption is the energy required to charge and discharge capacitive circuit elements. The power is proportional to the frequency with which the capacitor is charged and discharged, to the capacitance, and to the square of the voltage impressed on the capacitor. A gross estimate of the power consumption of the LMA cell, assuming a battery supply of 1.5 volts, a 1.5 micrometer CMOS process, 1500 transistors per cell, and a clock cycle of 80 microseconds, is about 1 microwatt. Therefore, 500 LMA cells can be incorporated into the processing structure at a total power consumption of about one-half milliwatt. This kind of structure is sufficiently complex for digital hearing aid applications and of sufficiently low power to use in an ear-level configuration.

Future Plans—Field studies with the body-wearable digital hearing aids will begin soon. The WDHA will be used to compare the performance of the digital hearing aid to that of conventional hearing aids under natural conditions of signal level and background noise. Selected patients will be fitted with the WDHA using the computer-based method developed for this project and also fitted with the best available commercial hearing aid. Patients will wear each aid for extended periods during normal daily activities. Patients will be asked to compare the two aids on the basis of signal clarity, comfort, and general utility.

The design of an LMA cell has been completed and has been submitted for fabrication. Testing to verify the accuracy of the design will begin in the near future. After the single LMA cell is tested, the design, fabrication and testing of a systolic array of LMA cells suitable for an ear-level aid will begin. Plans call for implementing the array in 1.5 micrometer CMOS to achieve the desired power characteristic.

Using a Psychophysical Model to Design Hearing Aids for Sensorineural Hearing Loss

E. William Yund, Ph.D.; Robert Efron, M.D.; Helen J. Simon, Ph.D.
Veterans Administration Medical Center, Martinez, CA 94553

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this research program is to characterize the suprathreshold auditory function of an individual with sensorineural hearing loss (SNHL) by means of a theoretical model of pitch processing (developed in our laboratory) and then to use that characterization to design a signal processing system to compensate for that hearing loss. If the results of the current research indicate that the model is useful in designing compensation systems—hearing aids—for SNHL subjects, the next major phase of the research will be the adaptation of these methods to the clinical setting.

Progress—The model was developed originally to explain aspects of pitch perception in subjects with normal hearing and then was shown to account for the results of a series of experiments on pitch perception in such subjects. Two factors suggest that the model may be useful in precisely defining the deficit in SNHL: 1) the close correspondence between the stages of the model and the functional parts of the peripheral auditory system thought to be damaged in SNHL; and 2) our development of psychophysical methods to measure the parameters of these critical stages of the model in normal-hearing human subjects. If the model accurately represents peripheral auditory function, then the model with parameters measured on a subject with SNHL becomes a model of his hearing loss which can be used to define the properties of a hearing aid fitted precisely to that loss. The hearing aid should be such that for any sound input, the hearing aid plus the hearing-loss model produces the same output as the (unaided) normal-hearing model. To the extent that an individual's hearing-loss model corresponds to that individual's hearing loss, it thus will define the appropriate hearing aid for that individual.

The hearing aid defined by the model (as

described above) for each particular hearing-loss subject is being tested using speech stimuli modified to simulate the action of the aid by means of digital signal processing software. These simulated hearing aid outputs are then generated with a digital to analog conversion system and presented to the subject through standard hearing aid receivers. The speech recognition performance of the SNHL subjects with their "aided" stimuli can then be compared with these subjects' performance on "unaided" stimuli and with the performance of normal-hearing (control) subjects with "unaided" stimuli presented under exactly the same conditions.

Preliminary Results—At this time, we have completed a series of psychophysical experiments, including those experiments needed to define the parameters of a hearing-loss model, on over 20 SNHL subjects. In addition, we have compared the performance of the "model hearing aid" with that of an individually-fit conventional hearing aid, using the methods described above, on half of those subjects. The results of these speech recognition experiments support the following conclusions. 1) Both the "model aid" and the conventional aid greatly improve speech recognition in low ambient noise conditions. 2) In a background of speech-band noise, the "model aid" performs at least as well as the conventional aid and, in most subjects, the "model aid" performance is superior to that of the conventional aid. 3) The greatest advantage of the model aid over the conventional aid occurs at low signal-to-noise ratios (+5, 0 and -5 dB), conditions where the SNHL patient usually experiences the most difficulty in understanding speech.

Current work includes testing the remaining subjects in the speech recognition experiments and detailed analysis of all of the data

obtained from these SNHL subjects.

Electroacoustic and Behavioral Studies of the Effect of Ear Impedance on Hearing Aid Performance

Vernon D. Larson, Ph.D., and William E. Cooper, Ph.D.

Veterans Administration Medical Center, Augusta, GA 30910 and University of South Carolina, Columbia, SC 29208

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this research is to study the relative acoustic impedances of hearing aid sound sources, the ear canal and the eardrum as they interact with the impedances of the earmold types, static pressure differences across the tympanic membrane, stapedial muscle contraction, and otic pathology.

Progress—A computer-based system (IBM PCXT) was assembled for the purpose of acquiring and processing acoustic data from ear canals. In addition, a computerized system for assessing the acoustic impedances, both real and imaginary parts, of sound sources has been developed and is now undergoing validation.

Data collection and analyses are in progress in three broad areas of study.

Ear Canal Sound Pressure Levels. The effect of ear canal volume and eardrum impedance (estimated tympanometrically) on sound pressure levels in the ear canal has been studied in relation to 2 ml coupler sound pressure levels. For subjects with small and large ear canal volumes, the sound pressures in ear canals (relative to 2 ml coupler levels) for frequencies below 1000 Hz were predicted by $20 \log ((V_e + V_c)/V_{2cc})$ while the sound pressures for higher frequencies (up to approximately 3000 Hz) were predicted by $20 \log (V_c/V_{2cc})$ where V_c = ear canal volume, V_e = eardrum impedance equivalent volume, and V_{2cc} = 2 ml reference volume. Investigations of the effect of ear canal volume while holding eardrum impedance relatively constant on auditory threshold are in progress.

Acoustic Reflex and Word Recognition Ability. The effect of the acoustic reflex elicited by a contralateral 6 kHz signal on word recognition ability has been investigated. Using an adaptive procedure to determine presentation levels at which 30 and 70 percent correct responses were obtained, activation of the reflex facilitated word recognition.

Alteration of Eardrum Impedance. The study of the effects of artificially altering the impedance existing in normal subjects at the lateral surface of the tympanic membrane is under way. In one series of studies, eardrum impedance was altered by varying the static pressure in ear canals. Sound pressure in ear canals averages an increase of 3 to 4 dB for frequencies below 1000 Hz while it decreases in the mid-frequency range. These ear canal sound pressure changes appear to be directly related to auditory threshold changes. In each case, however, the changes appear to be directly related to the electromechanical and acoustic properties of the sound source. In another study, static pressure changes in the ear canal have also resulted in an increase in the latency of the early components of auditory evoked potentials and median plane localization ability. In a third series of study, eardrum impedance (increased middle ear and intralabyrinthine pressures) was altered by placing subjects in a position wherein their heads were put downward and backward at an angle of 30 degrees. Ear canal spectrum levels increased by 2 to 6 dB in the 750 to 3500 Hz region.

Studies in Acoustic Feedback in Hearing Aids

David P. Egolf, Ph.D., and Vernon D. Larson, Ph.D.

Department of Electrical Engineering, University of Wyoming, Laramie, WY 82071 and Veterans Administration Medical Center, Augusta, GA 30910

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The causes of acoustic feedback in hearing aids are not well known and remedies for it are limited. The objectives of this project are 1) to study the causes of unstable acoustic feedback and to determine the physical and electrical parameters and interactions which affect it; 2) to study earmolds designed to reduce acoustic feedback and thus provide greater electroacoustic gain to the user; and 3) to design, build, and test prototype circuitry which suppresses unstable feedback.

Progress—The major project phases are complete. A computer model developed for this project includes: 1) an acoustic feedback path from the earmold vent outlet back to the hearing aid microphone; and 2) a direct acoustical path from the sound field to the eardrum (denoted by some authors as a feed-forward path) to account for sound entering the ear canal by the way of the vent. Computer generated and

measured field-to-eardrum transfer functions differ by, at most, 8 dB at some frequencies.

Preliminary Results—Three prototypes of the feedback suppression circuit have been produced and are now undergoing further electroacoustic and subjective evaluation on subjects. Preliminary tests indicate that this circuit, based on the "open-loop estimator" concept, reliably produces 6 dB additional stable gain when the hearing aid is coupled to a non-occluding earmold. With the same hearing aid configuration, investigators found that, with considerable fine-tuning this could be increased to 15 to 20 dB additional stable gain. Unfortunately, at these gain settings, the hearing aid became quasi-stable and minor acoustic disturbances (i.e., chewing or wind) would trigger the characteristic squeal of acoustic feedback. Other earmold configurations are now being evaluated.

The Laura Cochlear Implant

J. Marquet; S. Peeters; E. Officiers; W. Bosiers; M. Van Durm

University of Antwerp, Belgium

Sponsor: Universities of Antwerp (Antwerpen) and Louvain (Leuven), in collaboration with Forelec N.V. (Wilrijk)

Purpose—The two main parts of the Laura Cochlear Implant are separated by the skin. The external portion of the device consists of an input amplifier and speech processor, while the implantable portion is composed of the electronics and the multichannel intracochlear scala tympani microelectrode. The microelectrode is a platinum-iridium 16-wire electrode which is configurable as an 8-channel bipolar electrode or as a 1-to-15 monopolar electrode, depending on the control signals from the speech processor. The electrode is connected to an integrated circuit that decodes the incoming pulse-sequences. The electronics get their energy from an RF link through the skin.

Preliminary Results—The system is nearly as transparent as a percutaneous connector. Every 20 microseconds, the device is able to update any electrode with a new current value. (Most telemetry devices rely on simple inductive coupling or an amplitude-modulated carrier providing, essentially, only voltage control of their outputs. Only the most sophisticated telemetry devices allow current control.) On request of other groups, an impedance-measuring system has been built in to send information back through the skin.

The external system consists of a normal hearing aid for preprocessing of the signal, and the speech processor. The output of the hearing

aid goes to a set of bandpass filters which have been optimized by means of simulation experiments. Each filter includes a fast-attack, slow-release averaging circuit with a weighting function for every output. The outputs are scanned by means of a low power 8-bit analog/digital convertor (ADC) integrated in the low-power CMOS microprocessor. The scanning rate is locked to the pitch of the incoming speech signal.

The microprocessor uses the 8-bit ADC value to find patient-related values concerning the perceptive threshold of the patient, the discomfort level of the patient, and the nonlinear compression curve which is adaptable to the loudness perception of the patient. Values for

all eight channels are contained in nonvolatile (but erasable and reprogrammable) memory.

The built-in microprocessor allows flexibility to experiment with averaging phase-locking decoding or other decoding systems to match the optimum speech discrimination. The microprocessor could also compensate the travelling wave time of the basilar membrane. The total current consumption equals 15 mA.

Future Plans—The use of an electronic implantable device puts high demands on the packaging of the device, which is still under investigation. Future activities are expected to concentrate on testing and optimizing our biocompatible packaging.

Development of a Cochlear Prosthesis ---

F. Blair Simmons

Stanford Medical Center, Division of Otolaryngology, Stanford, CA 94305

Sponsor: *National Institutes of Health*

Purpose—The objective of this project is to create hearing and at least limited speech comprehension in totally deaf persons by electrical stimulation of the auditory nerve. Deaf human volunteers receive multielectrode implants within the inner ear. Basic psychophysical stimulation experiments measure the range of auditory precepts for each electrode and this data is then used as design criteria for the de-

velopment of computer-generated "speech processors" or acoustic feature detectors. The processors so developed are used to code speech sounds for electrical stimulation. Concomitant with this human research are animal experiments verifying the safety, tissue tolerance, and other features helpful and necessary for human research.

Matching Speech to Residual Auditory Function ---

Louis D. Braida

Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *National Institutes of Health*

Purpose—This research is directed toward improved signal-processing schemes to aid people with sensorineural hearing impairments. We intend either to develop improved schemes or to obtain a fundamental understanding of why such schemes cannot be developed. The proposed work includes study of linear amplification, amplitude compression, and frequency lowering. Also, attempts will be made to determine and understand the effects of variations

in speech production on speech reception by impaired listeners.

Progress—The research on linear amplification is concerned with modeling the dependence of speech-reception performance on the speech materials, the background interference, the listener, and the linear amplification system. Initial work on this project involves an attempt to apply articulation theory to speech reception by

impaired listeners.

The research on amplitude compression, directed towards listeners with reduced dynamic range, involves further study of multiband syllabic compression, as well as study of automatic volume control and limiting. The research on frequency continues to focus on pitch-invariant, nonuniform lowering. In both areas, the proposed work involves further exploration of the effects of various system parameters on speech-reception performance, testing of a wider variety of subjects, and attempts to determine the underlying causes of the results obtained.

The research on the effects of variations in speech production is motivated by our belief

that both intersubject and intrasubject variations exist that lead to substantially improved speech reception, and that an understanding of these variations and their effects will provide useful background for the development of improved signal-processing schemes. The proposed work in this area involves the development of speech materials uttered by different speakers under a variety of speaking conditions, the measurement of speech reception by impaired listeners using these materials under a variety of listening conditions, and the attempt to correlate the speech-reception results with properties of the acoustic waveforms.

Hearing Aid Characteristic Selection

Gerald A. Studebaker

Memphis State University/Audiology, Memphis, TN 38105

Sponsor: *National Institutes of Health*

Purpose—The overall purposes of the proposed research are 1) to study how the characteristics of amplified speech signals affect the performance and satisfaction of hearing impaired persons; and 2) to identify an adequate means to identify the characteristics an individual needs in order to obtain the most acceptable assistance possible. The two principal tools we will apply in these studies are subjective judgments and articulation theory.

Future Plans—Three different subjective methods will be used. First, a magnitude estimation-production method of evaluating speech intelligibility will be developed in order to produce band importance (BI) functions for continuous discourse and sets of nonsense sentences. Second, magnitude estimations of quality and intelligibility will be evaluated for reliability and validity with respect to intelligibility in a format designed for clinical use. The third method is an adaptive paired comparison procedure designed to run with a high degree of efficiency under computer control.

The adaptive paired comparison method

will be used to 1) investigate the relative importance of the characteristics of hearing aid reproduced sound to the acceptability of a hearing aid where acceptability is defined as the best combination of intelligibility and pleasantness; and 2) evaluate the intelligibility and other judged characteristics of new hearing aids or hearing aid types using juries of normal hearing persons.

Articulation theory will be used in an investigation of the relationship between the functional characteristics of frequency-by-intensity regions of impaired auditory systems and the speech intelligibility provided by those regions. Also, the distribution of the proficiency factor (PF) will be measured in narrowly defined linguistic groups. Finally, hearing aid performance will be evaluated using the concept of hearing aid efficiency in which frequency response and S/N ratio effects are "controlled" by the use of the articulation index. Standard and nonstandard measures of electroacoustic performance will then be related to hearing aid efficiency.

Rehabilitation Strategies for the Hearing Impaired: A Digitally Programmable Master Aid

Harry Levitt

CUNY Graduate School, New York, NY 10036

Sponsor: *National Institutes of Health*

Purpose—Rehabilitation strategies for the hearing impaired will be developed and evaluated. Strategies for speech and auditory training of hearing impaired children and adults will be considered. The impact of tactile and visual sensory aids on learning rates will be investigated and new types of sensory aids will be developed, including computer-simulated experimental hearing aids and wearable multichan-

nel tactile displays. Methods of rehabilitation training for cochlear implant recipients will be developed and evaluated. Analytic and global methods of training will be compared. Comparisons with tactile aids and conventional hearing aids will also be undertaken. The proposed research should result in improved rehabilitation techniques for a wide range of hearing impairments and methods of intervention.

High-Frequency Acoustics in the External Human Ear (Phase I)

George F. Kuhn

Vibrasound Research Corporation, Aurora, CO 80014

Sponsor: *National Institutes of Health*

Purpose—Recent research pertaining to 1) high frequency audiometry up to 20 kHz; 2) to the measurement of in-the-ear pressures produced by hearing aids; and 3) to the research and diagnostic applications of so-called cochlear distortion products have necessitated accurate knowledge of the acoustic wave motion in the external meatus.

The acoustic wave motion within the external meatus is a function of frequency, of the size (length, cross-sectional shape) of the canal, of the physical properties of the eardrum, of the eardrum inclination relative to the ear canal axis, of the location and impedance of the microphone to be used for the pressure measurement in the ear canal.

Future Plans—The proposed Phase I research is to collect a set of molds of the external meatus and of the conchae of human cadavers in order to determine the range of sizes and shapes of the canals and conchae and the inclination of the eardrum relative to the ear canal axis. The physical dimensions and shapes of these earmolds will be measured in order to design some scaled models which have acousti-

cally significant yet realistic features.

Initially, miniature microphones will be used to determine the acoustical significance or order of importance of each feature, such as curvature of the canal, eccentricity of the cross section, eardrum inclination relative to the canal axis, off-axis placement of the source, etc. Specific microphone designs will then be tested which will either cause a minimum of interference with the sound pressure at the microphone's location and at the eardrum or cause a systematic predictable deviation from the true pressure so that a proper correction can be made. Such microphones might be of a segmented, annular type or of a multi-element circumferential type.

Theoretical models will be used as a guide for such microphone designs in terms of shapes and placement and for the prediction of sound pressures at the eardrum. The long range goals for Phase II are to develop experimental and theoretical models for sound sources, microphones, and wave-propagation models in the external ear which extend to the high frequencies. The goal of Phase III is to produce such instrumentation commercially.

Multimicrophone Monaural Aids for the Hearing Impaired

Patrick M. Zurek

Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *National Institutes of Health*

Purpose—The ultimate goal of this research is the development of sensory aids which sample the acoustic environment at more than one point in space (multimicrophone aids) to improve the ability of hearing-impaired subjects to function more effectively in complex environments containing interference and reverberation. The more immediate goal is to explore the potential of multimicrophone systems for monaural listening in such environments. The results of this research, combined with research on binaural interaction in impaired listeners, will provide solid background for the development of multimicrophone aids to assist impaired listeners who have significant hearing in either one or two ears.

Future Plans—The proposed research, which draws heavily from previous work on both nat-

ural and artificial spatially diversified sensor systems (binaural hearing and antenna/signal-processing theory), is concerned primarily with reduction of interference and coding of spatially resolved information. The techniques considered for reducing interference include both linear and nonlinear processing, and both fixed and adaptive processing. The study of spatial coding, which is motivated by the need to monitor the general acoustic environment as well as to focus upon a particular source, is concerned with the extent to which signals that are spatially resolved physically can be processed for monaural listening so that the resolution is preserved at the perceptual level.

Results on the reduction of interference should be applicable to cochlear implant aids and sensory substitution aids as well as conventional acoustic aids.

Processor-Controlled Hearing Aid

Samuel Gilman

Sam Gilman Associates, West Los Angeles, CA 90025

Sponsor: *National Institutes of Health*

Purpose—The long-term objective of the proposed program is the development, design, and manufacture of a signal processor-controlled hearing aid to maintain the overall sound pressure level (SPL) and the spectrum at the eardrum within optimum limits of the hearing impaired individual for all expected input spectra and input levels. An additional feature will be an increase in signal-to-noise ratio of the aided signal.

Future Plans—The signal processing will be based on the actual eardrum SPL, determined from an acoustic feedback signal obtained by a microphone or probe in the ear canal. For all expected input levels, the spectrum of the ear-

drum sound pressure is controlled by the processor, so that the peak SPL in any $\frac{1}{3}$ -octave interval does not exceed the individual's loudness discomfort level (LDL) while still maintaining the desired spectrum and SPL at its most effective value. The processor compares the inputs and outputs for each filter, and the gain in each channel is then adjusted (on a real-time basis) to obtain the desired output for the band. Determination of averaging times for both the input and output signals are significant and will constitute a major element in the study. Phase I objective is to breadboard this system (without the signal-to-noise ratio improvement), and test it on a manikin equipped with an ANSI S3.25-1979 simulator.

Direct Measurement of Loudness Recruitment in Hearing-Impaired Veterans

Rhona P. Hellman, M.S.

Veterans Administration Outpatient Clinic, Boston, MA 02108

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The goal of the current investigation is to determine whether the psychophysical scaling procedures developed in the 1950s by S.S. Stevens for the measurement of loudness in normal hearing can be adapted for routine clinical testing and diagnosis of hearing impairment. To achieve this goal, a battery of psychophysical procedures has been devised to measure, assess, and predict the exponent of the loudness function in normal-hearing and hearing-impaired listeners. Prediction is based on the assumption that a transitive interconnected network of power-function exponents obtained for groups of people can also be obtained for individuals. To test this assumption, a systematic study of the relation among power-function exponents for individuals is necessary. Three different psychophysical procedures are used for the measurements: absolute magnitude estimation (AME), absolute magnitude production (AMP), and cross-modality matching (CMM). Measurements involve two sensory continua, perceived line length, and loudness.

Progress—In a first experimental series, lines of light that varied in length from 0.52 to 65 cm were constructed. Perceived line length was judged in total darkness (10 observers) and in partial darkness (17 observers) by AME. No statistically significant difference was found between the two viewing conditions. Data analysis showed that line length is a power function of physical length in cm. The mean exponent in total darkness was 0.96; in partial darkness it was 0.93.

Subsequently, to calibrate and standardize the line-length stimuli, a different group of 51 normal-hearing observers judged perceived length in partial darkness by AME. The same 51 observers also judged the loudness of a 1000 Hz tone by AME and by AMP. In addition, CMM was used to obtain the matching relation between the loudness of a 1000 Hz tone and

perceived line length.

Preliminary Results—Four sensation-magnitude functions, one for each series of measurements, were generated for each observer. Using the method of least squares, the results show that individual sensation-magnitude functions are well described by power functions to the form $\Psi = K\Phi^\Theta$, where Θ is the exponent of the power function. Perceived length is a power function of measured length with an average exponent of 0.96, loudness is a power function of sound pressure with an average exponent of 0.43 for AME and 0.67 for AMP, and CMM yields a power function between line length and loudness with an average exponent of 0.60. The geometric mean of 0.43 and 0.67 (AME and AMP) gives a measured exponent for loudness of 0.54, and the product of 0.96 and 0.60 (Perceived length x CMM) gives a predicted exponent for loudness of 0.58.

The average difference of +0.04 between the predicted and measured exponents is within the experimental error expected for psychophysical judgments. It amounts to a measured deviation of only 7 percent. Furthermore, the distributions of measured and predicted exponents closely agree. The measured exponents range from 0.32 to 1.14; the predicted exponents range from 0.33 to 1.02. Both the average exponents and the range of exponent values suggest that the battery of procedures standardized in normal ears is suitable for use in impaired ears.

In additional experiments, nine listeners with bilateral sloping high-frequency cochlear losses judged loudness by AME, and by AMP at two test frequencies in the normal-hearing region. The main objectives were to evaluate the loudness-growth range in detail, and to determine the appropriate test frequency for the measurement of loudness recruitment.

Future Plans—The results described in this report will be used as a basis for the development and implementation of a direct clinical

test of loudness recruitment. Future experiments will involve large-scale testing of hearing-impaired listeners.

Changes in Frequency Organization of the Cochlea During Aging

Brenda M. Ryals, Ph.D. and Edwin W. Rubel, Ph.D.

Audiology and Speech Pathology Service, Veterans Administration Medical Center, Richmond, VA 23249 and University of Virginia Medical Center, Laboratory of Developmental Neuro-Otology, Charlottesville, VA 22908

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Our hypothesis for the current project has been that changes in the place/frequency organization of the cochlea are taking place in late life. Specifically, we have hypothesized that a shift in the maximal stimulation pattern on the basilar membrane toward the apex occurs in old age. We think that this apical shift may be a fundamental mechanism in presbycusis or old age hearing loss.

Results—Our first experiment was designed to determine whether or not there was a functional correlate to the anatomical shift in frequency/place organization that we had reported. Chicks were exposed to a 1500 Hz pure tone at 125 dB SPL for 12 hours at two ages: post-hatch day 1 and post-hatch day 30. To reduce the biasing variables of survival time versus age, chicks were tested at both equal survival time and equal age. Our results show that the maximum position of hair cell loss was located differentially depending upon the age of stimulation. Chicks exposed early in life incurred a higher frequency maximum hearing loss than did chicks exposed later in life. These results were independent of survival time.

The second set of experiments has been designed to show the normal aspects of anatomical and electrophysiological changes in the Japanese Quail during aging. Anatomical analysis of the basilar papilla at the light microscope level at 45 and 85 days after hatch has shown a similar morphology to chick inner ear.

We have now determined an appropriate anesthesia/analgesic combination to use so that multiple AP threshold recordings can be made in the same animal over time. A t-Test for Homogeneity of Variance showed no significant

difference between initial and repeat tests. To date we have determined thresholds on birds at 3 months, 6 months, 2 years, and 3+ years of age (actuarial lifespan = 2 years). Results indicate no change in hearing up to 1 year of age. After 1 year of age thresholds gradually decline, particularly for frequencies above 1,000 Hz. A colony of animals is now established so that multiple measures of hearing can be made in the same animal over its own aging course. These results will be used to determine individual variability in threshold shift with age. Anatomical correlation of these evoked potential findings show no change in the number of hair cells present from 3 months to 3+ years of age as counted from 3 micron serial sections at the light microscopic level. The number of ganglion cells, on the other hand, decreases dramatically as a function of age. Further study of neural tissue is under way to determine if this degeneration is generalized or is specific to the auditory system.

Future Plans—We plan to complete our determination of the normal effects of aging on hair cell loss, ganglion cell loss, and auditory threshold shift during the lifespan of one species. These data are valuable to corroborate the generality of auditory acuity degeneration in vertebrates with aging. They will form the basis of the rest of our experiments on frequency organization. We also plan to investigate the influences of traumatic agents such as ototoxic drugs and/or noise during the aging process. These results will help determine whether chronological age acts synergistically with trauma.

After the normal effects of aging have been

determined, we will proceed to study possible frequency organization changes as a function of aging. If we see changes in a fundamental audi-

tory process such as place coding, it will have far reaching implications for the prevention and/or rehabilitation of hearing loss in old age.

Clinical Trials with the Cochlear Implant Prosthesis: Speech and Voice Characteristics, Part I

Jaclyn B. Spitzer, Ph.D.; Steven B. Leder, Ph.D.; J. Cameron Kirchner, M.D.; Frederick Richardson, M.D.; Paul Milner, Ph.D.; Carole Flevaris-Phillips, Ph.D.

Veterans Administration Medical Center, West Haven, CT 06516

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The main objective of this investigation is to assess acoustically and perceptually speech and voice characteristics of adventitiously profoundly deaf subjects and cochlear implanted subjects, both at the time of evaluation and longitudinally.

Progress—To date, 27 adventitiously profoundly deaf subjects have been seen for voice and speech evaluations. Eight subjects have had cochlear implants and three are awaiting surgery. Results showed that fundamental frequency was significantly higher, intensity significantly louder, and duration significantly longer in the speech of the adventitiously profoundly deaf than in normal-hearing control subjects. In

pre- and postimplant comparisons, longitudinal use of a cochlear implant significantly enhanced production of general American English contrasting stress patterns.

Future Plans—Continued longitudinal assessment of speech and voice characteristics in cochlear implant subjects will center on the acoustic features of voice-onset-time, consonant closure duration, vowel duration, vowel formants, and fundamental frequency. A perceptual study between adventitiously deaf and normal hearing subjects will be performed to determine the effect, if any, of adventitious deafness on speech and voice quality.

Clinical Trials with the Cochlear Implant Prosthesis: Speech and Voice Characteristics, Part II

Jaclyn B. Spitzer, Ph.D.; J. Cameron Kirchner, M.D.; Frederick Richardson, M.D.; Steven B. Leder, Ph.D.; Paul Milner, Ph.D.; Carole Flevaris-Phillips, Ph.D.

Veterans Administration Medical Center, West Haven, CT 06516

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The project is in the third year of a 3-year grant to develop evaluation methods and assess the rehabilitative benefits of cochlear implantation. The trials entail use of the 3M-House single channel device. Subjects undergo an intensive pre-implant evaluation protocol described previously. If selected, based on meeting rigorous criteria for profound sensorineural hearing loss without benefit of conventional amplification and other medical and psychological indices, the patient undergoes implantation. All implanted subjects undergo post-surgical rehabilitation and reevaluation to determine pos-

sible improvements in communicative function, handicap perception, and psychological status. A longitudinal (6-month and annually thereafter) design is employed.

Progress—Subjects in all phases of the protocol resulted in 33 admissions through the summer of 1986. Eight subjects have been implanted with the 3M-House device and received a course of 40 hours of post-fitting rehabilitation. The course consisted of auditory training with the new auditory code, training in synthesis of auditory and visual input, and counselling regard-

ing communicative strategies). Three surgeries were accomplished by the end of the summer. Nonselected subjects have received alternative rehabilitation, including powerful auditory or tactile aids.

Preliminary Results—Findings in pre- and post-implantation comparisons have demonstrated: 1) significant auditory threshold improvement following implantation; 2) highly variable improved abilities in word and stress recognition;

3) improved ability to control voice parameters, as reflected in appropriate production of contrasting stress, and fundamental frequency and duration values which approximated age norms. We also have shown the utility of a two-forced choice speech intelligibility task, and use of evoked potentials with stimuli presented via an auditory trainer. Final data analysis will focus on statistical prediction of cochlear implant candidacy.

Implementation of Digital Measurement of Aural Acoustic Immittance

David J. Thompson, Ph.D. and Larry N. Robinette, Ph.D.

Audiology Research Program, Dorn Veterans Hospital, Columbia, SC 29201

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is the evaluation and clinical implementation of a programmable acoustic immittance instrument. Immittance (impedance or admittance) is used with reference to measurements obtained in the ear canal and is displayed in admittance units (Y_a and phase angle, or B_a and G_a), with option for conversion to impedance units (Z_a and phase angle, or R_a and $-X_a$). This digital instrument is a computer peripheral (Micro Audiometrics MA1.1) with measurement capacities exceeding those of analog acoustic immittance instruments. Exploitation of the potential of digital measurement requires: 1) development of sophisticated control software on a host computer (IBM-PC); 2) laboratory validation of the hardware/software system and measurement protocols; and 3) clinical evaluation on normal ears and ears with hearing loss.

Progress—During the second year of the project, emphasis was on the development of research-oriented software using a single digital instrument. The software developed for this work used the high-level language called "BetterBASIC" (Summit Software). Routines were written in BetterBASIC for automated calibration and for acquisition, measurement, storage, and graphing of tympanograms and acoustic reflex responses. The acquisition mode includes the capacity for signal averaging, routines for

tympanograms, scaling of data, assigning of labels, finding maximum and minimum acoustic admittance, recording the location of maximum admittance, computing static admittance with phase angle, and computing the change in phase angle over the course of the tympanogram. Finally, acoustic reflex thresholds were determined through interaction with an on-screen display of the stackplots of acoustic reflex responses.

The amplitude and temporal characteristics of single acoustic reflex responses can be analyzed. Reduced data are also provided for the input-output function and perstimulatory adaptation. Summary data is derived from raw immittance data. All data are displayed on a single screen and can be saved to disk or printed out.

Preliminary Results—Laboratory assessment of the hardware/software system showed the digital AAI instrument to be more reliable and accurate than commercial acoustic-immittance instruments built with analog circuitry. The system is now being adapted for laboratory studies intended to explore and extend its limits. Other efforts have included initiation of a comparative study of digital and analog acoustic immittance instruments, and application of a commercial data analysis package (ASYST; Macmillan Software Company) to re-

duction of acoustic immittance data. Work in the final year of the project will concentrate on

the development of software to support clinical utilization of the digital instrument.

A Microprocessor and Signal Processor-Based Speech Training System for the Hearing Impaired

Cliff Kushler, MS

Funakubo Laboratory, Department of Precision Machinery Engineering, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, Japan 113

Sponsor: *Japanese Ministry of Education*

Purpose—The purpose of this project was to design and build a compact and inexpensive speech training system for the hearing impaired which is capable of providing visual feedback in a variety of training modes. The objective was to be able to provide support for each of the five stages in language acquisition defined by Daniel Ling: 1) abundant vocalization; 2) variation in intensity, duration, and pitch; 3) vowel and diphthong production; 4) consonants; and 5) consonant blends with respect to the target language, Japanese. To minimize costs and to facilitate the use of the system in a small group as well as an individual setting, all feedback is visual as opposed to tactile, and all input is done using microphones rather than sensors which must be physically attached to the user.

Progress—The first prototype built was a completely stand-alone system based on a Z-80 main processor and four NEC uPD-7720 signal processors, which can also be interfaced with a personal computer. The system is menu-driven and controlled by six pushbutton switches, and can be used independently even by fairly young children. A number of game-type displays are also under development. This system can provide training appropriate to the first three of the above stages. Real-time displays of variation in intensity, pitch, or a combined display of both can be generated along with a variety of standard or special targets. Vowel and diphthong training uses a real-time display (with a lag of less than 0.1 sec) of the first two formants in the F1-F2 plane which are extracted from the LPC spectrum. A microphone with a baffle is used as a nasality sensor, so that the

presence of excessive nasalization can be detected with respect to the first formant frequency, since a certain level of nasalance is natural in Japanese vowels with a low first formant. The level of nasality is reflected in the shape of the cursor in the F1-F2 display so a simple one-point display characterizes both vowel articulation and the level of nasalance. Preliminary field testing with this system indicates that significant progress can be attained even in a difficult subject (a congenitally profoundly deaf 11-year-old boy who remained undiagnosed and did not receive a hearing aid until the age of 7).

Future Plans—A second system is under development to provide training in the 105 consonant-vowel syllables of Japanese. This system is based on a 68000 microprocessor and two Fujitsu MB8764 high-speed signal processors. The current development system performs all of the required signal analysis, but the color displays are generated using a host personal computer. The display includes voicing and formant information, other spectral parameters including the center of gravity and spectral maximum, as well as a number of time domain parameters such as the short time energy and zero crossing rate. These are used to convey voicing and manner distinctions among the various consonants. Target patterns are being defined which will be temporally expanded or compressed to match the timing of the training attempt and simplify comparison. A simple heuristic algorithm for estimating the closed glottis interval is under development to aid in the attempt to extract place information from the acoustic signal and improve reliability of the spectral analysis in cases of high-pitched speech.

An Experienced User of Tactile Information as a Supplement to Lipreading: An Evaluative Study

Geoff Plant and Karl-Erik Spens

Speech Transmission Laboratory, Royal Institute of Technology, 100 44 Stockholm, Sweden

Sponsor: Royal Institute of Technology

Purpose—A 48-year-old Swedish male deafened by meningitis at age 8 has developed a unique method whereby he can perceive a speaker's laryngeal vibrations and use this information as a supplement to lipreading. The method consists of placing his hand on the speaker's shoulder with his thumb pressed lightly against the side of the neck.

Progress—Testing of the subject using this method revealed improvements in lipreading ability with materials ranging in complexity from nonsense syllables to connected discourse.

Testing via tactile stimulation alone showed that the subject was able to perceive consonant voicing almost perfectly (99.3 percent correct), and consonant manner of articulation was identified at a high level of proficiency. Performance with materials assessing perception of syllables in words and sentences and emphatic stress in sentences was also relatively high. Testing was also conducted using two experimental vibrotactile aids. Performance with these was consistently lower than that using the subject's own method across almost all testing materials.

The Effects of Cochlear Implantation on Speech Production

Geoff Plant and Anne-Marie Oster

Speech Transmission Laboratory, Royal Institute of Technology, 100 44 Stockholm, Sweden

Sponsor: Royal Institute of Technology

Purpose—An investigation was undertaken to determine if any changes had occurred in the speech of a Swedish female speaker 2 years after implantation.

Progress—The subject had been profoundly deaf for 10 years when recordings of her speech were made just prior to implantation. The subject was rerecorded using the same materials 2 years after implantation. Analysis of the recordings pre- and postimplant revealed that a number of changes had occurred after implan-

tation. At the prosodic level, these include a more normal range of fundamental frequency (F), improved F control in signaling emphatic stress contrasts, and improvements in durational aspects. Changes also were noted at the segmental level. These involved a generalized backwards shift of the subject's vowel space. This may, however, be attributable to training effects rather than the information provided by the implant. Subjective evaluations of the subject's vowel quality and overall speech quality also were undertaken.

A Single-Transducer Vibrotactile Aid to Lipreading

Geoff Plant

Speech Transmission Laboratory, Royal Institute of Technology, 100 44 Stockholm, Sweden

Sponsor: Royal Institute of Technology

Purpose—Four deaf subjects were tested using a vibrotactile aid to lipreading presenting voic-

ing information and a cue to signal the presence of high-frequency consonants. Testing at

the level of consonant perception presented lipreading alone, and lipreading supplemented by the aid showed improvements in the perception of consonant voicing and manner of articulation in the aided condition. Testing at the word and sentence level showed differing results for the subjects completing the tasks.

Progress—A congenitally deaf subject with a history of non-hearing aid use showed no improvements in the aided conditions, whereas another subject with a history of very success-

ful hearing aid use evidenced improvements in the aided condition for both sets of materials. Testing at the level of connected discourse revealed improvements in the aided condition for two subjects but equivalent scores aided/unaided for the subject with limited hearing aid experience. Testing in the tactile-alone condition showed that the subjects were able to perceive the presence/absence of /s/ and word syllable number and type with a high degree of proficiency.

Development of Materials for Computer-Assisted Instruction in Lipreading

Lennart L. Kopra, Ph.D.; Martha A. Kopra, M.Ed.; Judy E. Abrahamson, M.A.; Robert J. Dunlop, Ph.D.

University of Texas at Austin, Department of Speech Communication, Austin, TX 78712 and Olin E. Teague Veterans Center, Temple, TX 76501

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The goal of this program is to examine the effects of supplementary drill and practice with an auditory-visual laser videodisc interactive system (ALVIS) on the development of lipreading skill. A computer system has been designed, and software has been written for ALVIS and is being used for drill and practice in computer-assisted interactive video (CAIV) instruction in lipreading. The system includes: a laser videodisc player, microcomputer, keyboard, video monitor, two microfloppy disk drives, dot-matrix printer, external amplifier and attenuator, programmable attenuator with associated accessories, and earphones.

Progress—Twelve lists of 25 sentences each have been standardized and arranged in order of difficulty as lipreading stimuli. These five- to eight-word sentences were recorded on 1-inch videotape and then pressed on videodisc. Presentation of the 300 sentences is under software control by ALVIS in each of two conditions. In the first condition, no sound is given; word clues are presented on the video monitor for a

maximum of five trials. In the second condition, auditory clues accompany the visual stimulus (0 dB, 5 dB, 10 dB, and 15 dB, relative to the subject's binaural speech detection threshold) for a maximum of five trials. Student response data are recorded on microfloppy disk.

ALVIS is being used experimentally with postlingually hearing impaired adults in a program of aural rehabilitation which includes lipreading instruction. Six subjects received group lipreading lessons twice per week for 6 weeks. On days following group instruction, each of two subjects received lipreading drill and practice in one of three conditions: 1) with ALVIS clue words; 2) with ALVIS auditory clues; and 3) face-to-face with the lipreading instructor. Thirty-six subjects have participated in group listening instruction: 12 have received drill and practice with ALVIS word clues, 12 with auditory clues, and 12 face-to-face with the lipreading instructor. Data from this study are currently being analyzed to determine the effects of CAIV instruction on the development of lipreading performance.

Robotic Finger-Spelling Hand

Arthur Jampolsky, M.D.; J.A. Brabyn, Ph.D.; Deborah Gilden, Ph.D.

Rehabilitation Engineering Center, The Smith-Kettlewell Eye Research Foundation, San Francisco, CA 94115

Sponsor: *National Institute of Handicapped Research; The Smith-Kettlewell Eye Research Foundation*

Purpose—Telecommunication for those without sight or hearing poses especially severe problems. Some of these individuals can utilize volatile braille displays for remote communication, but in practice the majority of the deaf-blind lose their sight only after being deaf for an extended period, and are therefore more familiar with methods of communication used by the deaf than those used by the blind. Many of these individuals communicate by a technique known as finger spelling—similar to the sign language used by the deaf but with the principal difference that the person receiving the information places his hand over that of the person who is doing the “signing.”

Progress—We have recently undertaken a research project to determine the potential applications of robotics in this field. In collaboration with Stanford University and the Veterans Administration RR&D Center in Palo Alto, Dr. Deborah Gilden of our staff has arranged for the construction of a prototype robotic hand capable of performing the functions necessary for finger spelling. An earlier project along these lines was undertaken by the Southwest Research Institute, whose kindness in lending us their prototype we gratefully acknowledge. A

new prototype has been specially designed for research into the possible reduction of the necessary number of degrees of freedom. Each joint within each finger can be locked up, effectively eliminating any movement by that joint, so that methods of sending the desired codes utilizing fewer fingers and joints can be explored. Our initial studies indicate that it may be possible to eliminate two fingers and some joints on the remaining fingers, from the robotic hand. Initial testing of the prototype by deaf-blind individuals has been successful, and Mr. David Jaffe of the VA Rehabilitation Research and Development Center is currently constructing an appropriate computer interface for the device to enable our staff to perform the necessary evaluation studies with the simplified codes.

Our initial prototype uses electropneumatic activation to move the fingers via wire cables, but future versions will use simplified and less expensive means of electromechanical motivation. Possible applications of this technology include computer access, telephone communication, reading (in conjunction with optical character recognition), and face-to-face communication by deaf-blind individuals with those who are not familiar with the finger-spelling code.

C. Speech Impairment

Prescription Guide for Nonvocal Communication Devices

Cheryl Goodenough-Trepagnier, Ph.D. and Michael J. Rosen, Ph.D.

New England Medical Center Hospital, Boston, MA 02111 and Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *National Institute of Neurological and Communicative Disorders and Stroke; National Institute of Handicapped Research; M.I.T. Undergraduate Research Opportunities Program*

Purpose—A system has been developed which includes a set of computer-guided evaluation procedures, testing hardware, and processing

programs to guide selection of a most suitable augmentative communication device for a motor-disabled, speech-impaired client. The

purpose of this system is to cast current knowledge about appropriate prescription in a form which makes it readily useable by the clinician who is not necessarily experienced with this low-incidence disability.

Progress—The Tufts-MIT Prescription Guide includes client evaluation protocols (need, cognitive, and motor), a device evaluation protocol, and software which processes client and device information in various ways to come up with scores reflecting the predicted suitability of each device for the client. It also has the capacity to display information representing how each device could be expected to meet or fail to meet the client's needs. In addition, the system contains software which guides the clinician through the client evaluation procedures, so that the clinician has no need to become familiar with the workings of the processing software. The current version of the Prescription Guide completed pilot testing by August 1986, and revisions, if indicated, and documentation were completed by October 15. The system was then operable for assessment of clients who are candidates for using devices which include the

alphabet. Device evaluation to date has included 27 electronic aids and numerous personal and standard inert language boards.

Pilot testing of motor and cognitive evaluations have been carried out with at least 20 nondisabled and 20 motor-disabled, communicatively impaired people. Cognitive assessment tools developed for this project evaluate spelling and learning of new verbal associative and spatial information, without requiring spoken or complex motor responses. Motor assessment protocols and hardware measure the dependence of movement time on the physical parameters which characterize planar keyboard devices, reaction time with preview for switch closure and closure-release-closure, and inter-switch closure time using pairs of body sites. Assessments for breath pressure and EMG as control modes are also included. These data are processed to predict user device communication rate ceiling.

The next stage of work will focus on finding a commercial distributor, and on further development of the system to make it applicable to children and people with more severe cognitive and perceptual impairment.

DEXTER: A Mechanical Finger-Spelling Hand for the Deaf-Blind

Deborah Gilden, Ph.D., and David L. Jaffe, M.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The explosive growth of technology has provided new methods of electronic communication and has increased the amount of information to which people are exposed. Unfortunately, however, the new channels of information exchange are not always readily available to individuals with sensory disabilities, resulting in a widening gap between them and the able-bodied community. In particular, the needs of deaf-blind individuals have not been adequately addressed.

Communication with deaf-blind individuals is most often accomplished with the aid of a human interpreter. When using finger-spelling, each letter to be communicated is represented by a particular hand and finger position as de-

fined by the One-Hand Manual Alphabet. The words are spelled into the palm of the deaf-blind listener, one letter at a time.

While this tactile mode of communication allows for interactions with those familiar with the technique, it does require the presence of and direct contact with an interpreter. Without such human aid, the contents of books, magazines, and other printed documents are inaccessible to the deaf-blind individual. In addition, able-bodied persons who do not know finger-spelling are unable to engage them in effective communication.

Few aids have been developed for those with the double sensory impairments of blindness and deafness. Aids for people with im-

paired vision or hearing cannot alleviate the isolation, dependency, and restriction of activities experienced by those who are both deaf and blind, since those devices typically employ either a visual substitution system for the hearing impaired or a sound substitution system for the visually impaired. However, devices which harness the tactile channel would improve the quality of life for deaf-blind individuals.

Progress—In 1978, the Southwest Research Institute (SwRI) in San Antonio, Texas, developed a mechanical hand designed to form the symbols of the deaf-blind finger-spelling alphabet on command from a standard keyboard. It sought to mimic the finger positions produced by a human interpreter engaged in finger-spelling. During the testing phase, subjects were able to identify a majority of the letters reliably, but disagreed on the finger positions corresponding to others. They also experienced difficulty during the hand's flexion and rotation maneuvers and when the letters were presented too rapidly.

It was proposed that the initial SWRI concept could be improved upon by the power and flexibility provided by microcomputer technology to resolve the problems of their prototype unit. Smith-Kettlewell sponsored a Stanford student project in a graduate-level class in Mechanical Engineering: Dexter, an improved mechanical hand, is the result of that effort. The mechanical portion of the hand is similar to the SwRI device. Each finger operates independently of the others and has a range of motion comparable to that of human fingers. All finger and thumb motions are actuated through drive cables pulled by pneumatic cylinders; spring-driven return cables open the finger joints to the extended position.

A microcomputer and companion software control the opening and closing of valves which operate the pneumatic cylinders. Each letter is

formed by a timed sequence of these valve operations. Letters to be displayed are typed on the computer's keyboard. The inclusion of the microcomputer will allow the optimization of timing and finger motions during the design and evaluation phases.

Preliminary Results—On May 29, 1985, feasibility tests were conducted with two subjects at the Lions Center in Oakland, California. One consultant was blind and deaf; the other was blind but had partial hearing. Each test session began with a 30-minute period in which the subjects were allowed to become acquainted with Dexter. During that time, the hand's purpose and motions were related to the testers by a human interpreter. By the end of each session, both subjects could recognize most letters and could read complete sentences from the hand.

Current activity is concerned with the replacement of the Stanford-owned computer system with a Zilog-based microcomputer system donated by Prolog Corporation. The software has been rewritten to 1) to achieve software compatability with the new hardware; 2) to accomodate changing of critical parameters such as timing variables; 3) to allow new characters to be accepted while previous ones are being displayed; 4) to permit easy modification of finger movements for any letter; and 5) to incorporate both modem and serial input of characters.

The current project has built upon the successes of the previous tactile aid and contains features which overcome the deficiencies noted by its users. In particular, timing factors and the adjustability of finger positions have been addressed. The resultant device has potential application in facilitating interpersonal interactions, in making computer-based information more accessible, and in promoting increased telephone communication.

A Study of Speech Intelligibility Over a Public Address System

Fred J. Lundin

Speech Transmission Laboratory, Royal Institute of Technology, 100 44 Stockholm, Sweden

Sponsor: *Royal Institute of Technology*

Purpose—Speech intelligibility over the public address system at Arlanda Airport, Stockholm, has been calculated by different methods. The articulation index method (AI) is based on frequency characteristics and provides merely a rough correction for room reverberation. On the other hand, a method suggested by Peutz (1971) and by Klein (1971) based on room acoustics, does not employ frequency characteristics. A compromise is the SRR-method presented in this paper, which utilizes the direct-to-reverberant sound intensity. It is based on the theory of Peutz and extended to handle the sound levels of the direct sound, of the reverberant sound, and of the noise. The analysis is performed in frequency bands and is applicable to rooms with multiple sources and ambient noise. Finally, the method of modulation transfer function (MTF) has been used. By this method the reduction in modulation depth of speech signals

within separate octave bands caused by reverberation is calculated. It is more complex than the other methods. The outcome from these four prediction methods has been compared to measured values recorded by use of a dummy head in two rooms and evaluated by a listening group of ten people. The intelligibility is tested at two background noise levels (with a signal-to-noise ratio of 10 and 20 dB, respectively).

Results—The results show a fairly good agreement between measured and predicted data of lower speech levels but when both noise and reverberation interfere, the methods will underestimate the articulation loss. Under these conditions the MTF-method will give the most appropriate result. Our study also indicates that the more complex methods are not much superior to the simpler ones.

Measurement and Prediction of Benefit from Amplification

Robyn M. Cox, Ph.D.; Kay M. Pusakulich, M.A.; Genevieve C. Alexander; Christine Gilmore, M.A.

Department of Audiology and Speech Pathology, Memphis State University, Memphis, TN 38152 and Memphis Veterans Administration Medical Center, Memphis, TN 38104

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The objective of this project is to develop and validate a test of intelligibility of everyday speech—the Connected Speech Intelligibility (CSI) Test. The project plan calls for four major experimental phases. 1) Investigation of the intelligibility characteristics of a typical talker and selection of a typical talker to record the initial pool of test items will be made. 2) Generation of the initial pool of CSI test items. Seventy-two passages of connected speech will be audio-visually recorded. Forty key words per passage, having a range of identification probabilities, will be empirically determined. Twenty normally hearing subjects will participate in this phase; 3) Generation of final CSI test forms. Twenty to 30 hearing impaired sub-

jects will respond to test passages generated in phase two. Twelve equivalent test forms will be developed by combining passages into 12 groups having essentially equal means, variances, and correlations with true score; 4) Evaluation of final CSI test forms. Thirty different hearing impaired subjects will listen to the test forms generated in phase three. Scores will be analyzed to determine equivalence and reliability data for the final test forms. In addition, relationship between monosyllabic word recognition scores and CSI scores will be investigated.

Progress—Phase one has been completed. Three male and three female talkers participated in this study of the intelligibility of average

talkers producing conversational speech in four different everyday listening environments. The four environments were characterized by: low noise/low reverberation; low noise/high reverberation; high noise/low reverberation; and high noise/high reverberation.

Preliminary Results—Preliminary results indicate that the intelligibility of the six talkers

differed significantly but that the rank order of talkers' intelligibility tended to remain the same across environments. Intelligibility tended to remain the same across environments. Intelligibility of eight speech features was analyzed for each talker. These data were used as the basis for selection of an average talker. Investigations required for phase two have been initiated. No results are yet available.

The Application of Microcomputers for the Treatment of Aphasic Adults

F.L. Loverso, Ph.D. and T.E. Prescott, Ph.D.

Harry S. Truman Veterans Administration Hospital, Columbia, MO 65201 and Veterans Administration Medical Center, Denver, CO 80220

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The use of microcomputers in rehabilitation of brain damaged patients continues to win popularity in some clinical settings. Cost effectiveness, operational efficiency, and increased treatment-time allocations without additional human resources are the high tech features which bolster their acceptance and application. Yet databased research in speech/language pathology concerning treatment efficacy remain sparse. In this age of high tech applications to almost every phase of our professional lives, there appears an urgent necessity to know the efficacy of treating patients with microcomputers. The field presently lacks convincing data as to the efficacy of using microcomputers for the rehabilitation of aphasic adults. It is unfortunate, however, that many clinicians are getting into the computer business without collecting this efficacy data first. The purpose, then, of the present study is designed to answer the following question: Are microcomputers more effective in teaching a criterion performance than the same procedure presented by a clinician?

Progress—The study population is being made up of 20 chronic aphasic patients who have sustained a single lesion to the left hemisphere. Each aphasic person within this study population will be in the mild to moderate range of aphasia severity. To study treatment effectiveness an alternating treatment design with mul-

tle problems (single case) is utilized. By using this type of design, baseline performance, the effects of treatment, maintenance of behavior, and generalization can easily be viewed. All patients receive two modes of treatment (clinician and microcomputer) daily in a rapid alternating fashion.

The microcomputer and clinician treatment packages are identical in terms of types of stimuli, modality and randomization of presentation, type of feedback, and scoring. The treatment itself is a well established protocol which has been demonstrated to be effective with this population of patients. In this treatment approach, verbs are presented as pivots and wh- questions provide strategic cues to elicit sentences in an actor-action-object framework. There are six hierarchical levels to this program ranging from copying a subject + verb combination to self-generation of subject + verb + object sequences. This treatment paradigm, in the traditional patient/clinician environment, is now being used nationally with adult brain injured patients as well as with children with specific language and learning disabilities.

Preliminary Results—As of June 1, 1986, 7 of the 20 patient/subjects have been entered into the study and have completed the treatment package. For all subjects studied, the clinician mode was more efficient in bringing the apha-

sic subjects to criteria than was the computer mode. On the average it took approximately twice as many sessions with the computer versus the clinician to complete this treatment protocol. Noteworthy is that although the clinician was far more efficient in terms of total visits, the microcomputer was shown to be an effective treatment tool for this particular protocol. Maintenance of behaviors were observed across all clinician treatment levels and four of the six treatment levels via computer presentation. Generalization to standardized language tests were also observed with statistically significant ($p < .01$) improvement noted between standardized overall test scores for treatment levels compared to the stable baselines in the clinician mode of treatment. These gains have been maintained by the patient/subjects for 3 months following termination of the treatment.

In each case thus far, the computer mode has been far less flexible in terms of stimuli and wh- cue presentations than in the clinician

mode of treatment. It appeared that when the patient/subject interacted with the computer, the patient's ability to control stimuli presentation was much faster than for the clinician-controlled stimulus presentation. In addition to the comparative results of clinician versus microcomputer, the present study is a systematic replication of our previous work for the clinician mode of treatment, indicating that this treatment approach is a viable protocol in the rehabilitation of brain injured aphasic adults.

Future Plans—Research needs to continue on measuring the effects of this program with more subjects, more types of aphasia, and more severity levels of this disorder for both the clinician and computer modes of treatment. These future efforts should make available a reliable, effective treatment program for both the microcomputer and clinician modes of treatment in the rehabilitation of aphasic adults to other facilities with similar case loads.

Drawing: Its Use as a Communicative Aid with Aphasic and Normal Adults

Jon G. Lyon, Ph.D.

Rehabilitative Medicine, Veterans Administration Medical Center, Reno, NV 89520

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Aphasic adults who remain functionally nonverbal, despite an understanding of common spoken language, have been restricted to communiques where the normal participant searches for probable intents through 'yes-no' questions. Although some of these expressively restricted aphasic adults have successfully incorporated gestures, many still remain noncommunicative. Drawing represents an avenue that might enhance communicative skills with aphasic adults who appear to possess the internal concept they wish to express but lack adequate verbal or gestural abilities to express it. Earlier case studies of the use of drawing with such patients have been reported in the literature. These studies have pointed to either the spontaneous appearance of drawing in the aphasic adult's communicative attempts or the successful incorporation of it as a treatment aid. However, a systematic, detailed examination of the

worth of drawing as a communicative tool has yet to be explored with a larger subject sample.

The purpose of this investigation is to assess the value of drawing as a communicative aid with a sample of ten expressively restricted aphasic adults, before and after a 3-month treatment period. In addition, a comparison of the drawing skills of aphasic adults to those of normal adults, using dominant and nondominant hands, was obtained.

Progress—To date, five expressively restricted aphasic adults and five normal adults have completed the study protocol. Findings suggest that aphasic adults demonstrate marked improvement in communicative effectiveness simply through the exposure to drawing as a communicative aid (comparison of drawing versus nondrawing communication, pre-treatment). Further communicative gains were ob-

tained following the 3 month treatment period. Normal adults drew well enough to successfully communicate their intent (verbally they were restricted to the use of "yes" or "no") whether using dominant or nondominant hands. Should

these trends hold for the remaining half of the subject samples to be collected, we propose to study generalization of communicative gains to nonclinical, natural settings.

Maxillofacial Prosthetic Management of Neurogenic Tongue Dysfunction

Michele J. Saunders, D.M.D., and Carol A. Venus, Ph.D.
Veterans Administration Medical Center, San Antonio, TX

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to determine whether the mastication, swallowing, and speech of patients with neurogenic tongue dysfunction will be improved by maxillofacial prostheses designed to compensate for reduced tongue function.

Future Plans—From dysarthric and dysphagic patients referred to speech and hearing clinics at two VA medical centers, patients with speech articulation profiles consistent with tongue dysfunction and oral stasis of oral intake following swallow will be selected. During the preprosthetic phase of the study, complete or partial dentures will be modified or fabricated to assure adequacy of fit. Then, baseline tongue function will be assessed, with and without the prosthesis in place, through 1) examination of the oral peripheral mechanism; 2) palatography; 3) modified barium swallow; and

4) intelligibility and articulation tests. During the prosthetic phase, the contour of the palatal surfaces of the prostheses will be modified to facilitate lingua-palatal contact during mastication, swallow, and speech. Final extent of modification will be determined by results of 1) articulation tests; 2) palatography; 3) patient report; 4) clinical swallowing evaluation; and 5) modified barium swallow. Patients will be followed by a speech pathologist and dentist until they are stabilized in terms of acclimation to the prosthesis and refinement of speech and swallowing with prosthesis in place. During the postprosthetic phase, measures of tongue function taken during the preprosthetic phase will be repeated. Statistical comparisons will be made of measures of mastication, swallowing, and speech with and without the prosthesis, and before and after modification/fabrication of the prosthesis.

Efficacy of Remote Treatment of Aphasia by TEL-Communicology

Gwenyth R. Vaughn, Ph.D.; Walter W. Amster, Ph.D.; John C. Bess, Ph.D.; Douglas J. Gilbert, Ph.D.; Kevin P. Kearns, Ph.D.; Amy Key Rudd, Sc.D.; Angela A. Tidwell, M.S.

Veterans Administration Medical Center, Birmingham, AL 35233

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Four Veterans Administration Medical Centers participated in an investigation designed to compare the efficacy of remote treatment of aphasia by TEL-Communicology (TEL-C) with traditional face-to-face treatment. Only patients who had suffered a left hemisphere cerebral vascular accident were admitted. Those who met selection criteria were assigned randomly to either the traditional face-to-face

treatment program or to the treatment program delivered by TEL-C. Any patient who rejected the group placement selected for him by the randomization process was given the option of entering a self-selected group that received treatment by the other delivery system. This option resulted in the formation of four groups—two randomized and two self-selected.

An evaluation battery of language meas-

ures was administered at entry, 8, 16, and 24 weeks. Neurological evaluations were administered upon entry and upon completion of the 24 weeks of treatment. Any time a change in the performance of a subject was detected, an interim neurological evaluation was undertaken. For those subjects who did not complete the entire treatment period, the information recorded at each 8-week evaluation was reported under 8- or 16-week cohort data. These data were analyzed separately for each group. As a result of having the four groups, it was possible to increase the number of subjects in the project, and to establish whether there were any differences between the randomized and self-selected groups. All subjects received 5 hours of treatment a week for 6 months, or for as long as they remained in the study. Two groups received treatment delivered face-to-face; two groups had treatment delivered by a combination of clinician-assisted and REMATE computer-assisted delivery (Remote Machine-Assisted Treatment and Evaluation).

Progress—The data showed no differences between the face-to-face and the TEL-C groups, nor between the randomized selection and self-selection groups in regard to age, education, or initial severity levels. All groups improved during the treatment period, and there were no significant differences in the amount of change from pre- to posttesting. It appeared that face-to-face and TEL-C treatments were equally effective. TEL-C groups also did slightly better in auditory functioning than the face-to-face

groups.

What strengthened the argument that TEL-C was as effective as face-to-face treatment was the fact that all the significant differences found were in favor of TEL-C. There were no significant differences in favor of the face-to-face groups. The use of restrictive criteria greatly reduced the number of subjects. If the number of subjects had been larger, the differences in favor of the TEL-C groups would probably have been more conclusive. In view of what evidence was available, it was apparent that TEL-C served as an effective delivery system for treatment, especially in the areas of verbal and auditory skills.

Preliminary Results—The RR&D study showed that on a national basis, the VA traditional face-to-face delivery was 17 percent more costly than TEL-C clinician-assisted delivery and 110 percent more costly than TEL-C REMATE-assisted delivery. A study of the annual cost savings per 1,000 patients for a national TEL-C program for the Veterans Administration showed that TEL-C clinician-assisted delivery saved \$3,626,393, and that TEL-C REMATE computer-assisted delivery saved \$5,091,316 for each hour of treatment delivered. Three hours of treatment a week are often recommended for patients with communicative disorders. The savings over face-to-face delivery for 3 hours of treatment a week for 1,000 veterans would be \$10,879,179 for TEL-C clinician-assisted delivery and \$15,273,948 for TEL-C REMATE computer-assisted delivery.

Computer-Aided Visual Communication for Severely Impaired Aphasics

Richard D. Steele, Ph. D., and Michael Weinrich, M.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Aphasia is the loss (partial or total) of ability to use one's natural language(s) for receptive or expressive communication. The loss arises from damage to the language processing faculties of the brain. There are approximately 84,000 new cases of aphasia each year, due primarily to cerebral vascular accidents

(strokes) and to traumatic head injury (as from motorcycle accidents). Because of improved treatment and better medication, individuals are surviving such occurrences in greater numbers, and subsequently are living longer. Despite current speech rehabilitation work, approximately half the new cases of aphasia each

year remain severely language impaired, and these individuals need some new form of communicative assistance.

This project aims at the ultimate development of an entirely new alternative communication device for severely impaired aphasics. This device would allow such persons to communicate thoughts which are currently beyond their communicative abilities, using pictographs and a language-like grammar. The work is also expected to help neuroscientists specify more precisely the nature and extent of preserved cognitive ability and communicative function which can coexist with global language impairment.

This work builds upon earlier studies using pictographs drawn on index cards. In the mid-70's, neurologists and aphasiologists in Boston and New York, inspired by special languages developed for chimpanzees, investigated two similar visually based communication systems. Both research groups found subjects who could learn to use the visual communication systems and employ them in selected communicative tasks. Subjects' performance using these systems far surpassed performance in English on equivalent tasks. Error rates among successful trainees were found to be low, and the patterns of error were similar across subjects, and stable. Despite positive clinical findings, the systems were almost never used by subjects outside training sessions, being judged cumbersome, demanding to use, and of limited practical utility.

Our three hypotheses are: 1) that by building on previous experience, we can develop a functionally useful Visual Communication (VIC) system, which will be operable by many severely impaired aphasic individuals; 2) that the use of contemporary computer technology will permit this computerized VIC (C-VIC) system to be implemented on a portable device;

and 3) that severely impaired aphasic persons using the C-VIC system will communicate more effectively than they will using any alternative means of communication.

A high-resolution screen allows the construction of easily recognizable pictographs, or icons. The sole use of the "mouse" pointing device, operable by one hand, makes operation of the interface accessible to subjects with the common right hemiparesis. Parsing and other language processing routines make the generation of natural-sounding English translations possible, and the eventual incorporation of Artificial Intelligence routines will make possible contextual cueing of the subject, appropriate new forms of feedback, and heuristic analyses of transactions.

Preliminary Results—A first version of the C-VIC system has been implemented on a Macintosh XL (LISA) computer, and we are currently training two severely aphasic subjects in its use. Our work to date has demonstrated that: 1) both subjects can perform, using C-VIC, at a level far exceeding their capabilities in equivalent tasks using English; 2) both subjects can discriminate between, and respond appropriately to, commands, statements, and questions; 3) both subjects have been able to master the principles of the computer interface operation quickly and accurately; and 4) the time required to access and correctly place an icon on the computer is acceptably short and consistent. An improved version of C-VIC is now being developed on the more portable Macintosh computer. It will allow greater resolution of icons, greater flexibility in the structure of the lexicon, a second tier of blank communication icons to allow more communication space for both investigator and subject, and more powerful language processing routines.

Effects of Real-Time Biofeedback on Dysarthric Speech

James A. Till, Ph.D. and Richard W. Light

Veterans Administration Medical Center, Long Beach, CA 90822 and University of California College of Medicine, Irvine, CA 92716

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The goals of this research are: 1) to develop and test the effectiveness of computer controlled real-time high resolution color visual biofeedback in inducing mild to moderate changes in respiration and speech rate among dysarthric patients; and 2) to measure other speech parameters that may covary with changes in speech rate and respiration. Of particular interest are changes in speech intelligibility that may occur with changes in speech rate and respiration. Cerebellar ataxic and Parkinson subjects will be compared to normal control subjects during time-series experiments. Measures of vocal fold movement, fundamental frequency, speech intensity, and speech intelligibility will be made in addition to the measures of speech rate and respiration. Simultaneous real-time extraction of all parameters except intelligibility and rate will be made by dedicated analog instruments connected to a laboratory computer.

Progress—During the first year, project personnel, all analog instrumentation, and computer

hardware have been acquired. Software for calibration, data acquisition, data achieving, and data analyses has been written and validated for speech parameters and aerodynamic signals. We are currently working on derivation of valid weighting factors to allow accurate noninvasive measurement of speech respiration through monitoring of abdominal and chest-wall movement.

Concurrent speech respiration and speech rate data have been collected for a group of normal adults in order to investigate the effects of speaking task variables on the measures proposed in this research. The effects of reading versus monologue, linguistic structure, and phonetic composition have been studied in a group of normals and selected dysarthric subjects. The results suggest that extreme variations in phonetic and linguistic structure are necessary to induce unusual speech respiration. However, monologue talking and oral reading do result in different patterns of speech respiration and speech rate for many subjects.

Experimental Analysis of Acquisition and Generalization of Syntax

Patrick J. Doyle, M.A.

Veterans Administration Medical Center, Pittsburgh, PA 15206

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project was to evaluate the effects of a syntax training program on the speech production skills of four Broca's aphasia patients and to socially validate the treatment effects by having naive judges rate the "adequacy" of responses before and after treatment.

Preliminary Results—Subjects were trained to produce five exemplars of five sentence types from *Helm's Elicited Language Program for Syntax Stimulation* (Helm-Estabrooks, 1981).

Experimental control was demonstrated by employing a within-subject multiple baseline design across sentence types. A multiple probe technique was utilized to pinpoint the occurrence of generalization and maintenance of trained sentence types to novel exemplars and novel stimulus conditions. In addition, naive judges rated subjects' responses on wh- interrogative and declarative responses before and following treatment in terms of their communicative "adequacy."

Rapid acquisition, with generalization

within response classes, was replicated across three subjects for five sentence types; the remaining subject demonstrated generalization for three of the five sentence types trained. Maintenance and generalization to nontrained stimuli, to conversational speech, and to novel setting conditions was limited to all subjects. Under experimental conditions, adequacy judgments revealed improved communication skills for wh interrogatives but limited changes in the perceived adequacy of subjects' declarative responses. These findings indicate that the effects of syntax training procedures are limited to those grammatical constructions taught, that generalization of learned forms to novel stimulus conditions is not an automatic consequence of acquisition, and that the effect of such training on the adequacy of subjects' responses may be limited.

Future Plans—Funding has been obtained to continue to empirically evaluate treatments that promote functional language use in aphasic adults. The overall purpose of the research is to determine whether programming specifically designed to promote generalization will have an effect on the verbal behavior of adults with acquired aphasia under conditions of spontaneous language use across a variety of natural contexts. Three separate investigations employing single case methodology will address the programming techniques of loose training, incidental teaching, and programming common stimuli. The results from these studies will allow us to generate hypotheses concerning the relative strength of critical variables and to identify variables necessary for the generalization of language training to other situations to occur.

XIV. Head Trauma and Stroke

Efficacy of Multiple Input Phoneme Therapy in the Treatment of Severe Expressive Aphasia

Elaine R. Stevens, MA, CCC-SP

Speech Pathology Section, Veterans Administration Medical Center, Togus, ME 04330

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—Stroke patients who display severe to profound expressive aphasia frequently fail with traditional treatment approaches. A new treatment technique, Multiple Input Phoneme Therapy (MIPT), has shown initial promise as an effective treatment technique for such patients. The purposes of this project are to: 1) demonstrate that patients classified as severely expressive aphasic will develop single word and phrase level communication as a result of MIPT; 2) demonstrate that concomitant changes in other modalities will occur as a result of MIPT; 3) develop a specific word list based on the MIPT hierarchy that can be used by other speech and language pathologists; and 4) study the length of time necessary for pa-

tients to complete the 22 steps in this therapy program.

Progress—Subjects diagnosed as having severe to profound expressive aphasia were randomly assigned to either a traditional or experimental treatment group. Each subject was seen two to three times per week for a 9-month period. Performance levels were carefully documented prior to treatment and at specific intervals.

Preliminary Results—Work completed to date indicates that subjects receiving Multiple Input Phoneme Therapy reached higher communicative performance levels than did those subjects receiving traditional therapy.

An Evaluation of a Microcomputer-Based Cognitive Rehabilitation Program for the Severely Head-Injured

Seldon H. Curry, Ph.D.

Burden Neurological Institute, Stoke Lane, Stapleton, Bristol, England 8516 1QT

Sponsor: *The Frances and Augustus Newman Foundation and the Head Injury Recovery Trust (H.I.R.T.)*

Purpose—A microcomputer-based cognitive rehabilitation program has been developed to assist the severely head-injured patient to make as full and—if intervention begins shortly after trauma—as rapid a cognitive recovery as possible. Patients enter the program either as soon as possible after the trauma (usually upon emergence from a post-traumatic amnesia of at least a week) or after several years of recovery. The basic idea of the cognitive rehabilitation is the provision of a structured and progressive set of stimulating and intellectually challenging material designed to exercise the more general areas of cognitive impairment subsequent

to cerebral trauma (i.e., attention span, attention control, impoverished memory, slowness, logical problem solving).

Progress—Because of a large number of factors—both theoretical and economic—it was decided that the material should be presented by a small, relatively inexpensive microcomputer. One of the primary factors influencing this decision was the desire to design a rehabilitation program that could be primarily home-based. In this program the patients have, purchase, or are loaned a relatively inexpensive microcomputer (Acorn BBC Models Master B or its re-

placement, the Master) and the necessary peripheral equipment (a high resolution color monitor and a Modem). A network system has been developed that allows each of the remote machines in a patient's home to be linked to a central computer at the Institute, using modems over the standard telephone lines. The network system provides both continuous control over the patient's rehabilitation program and complete monitoring of the patient's performance. The system is designed so that the telephone link is connected only for the transmission of programs and the receipt of results. This ensures that telephone charges do not become unreasonable, even for quite remote users.

As the rehabilitation program has been developing over the past 3 years, the pressures of development have allowed only cursory objective evaluation of the therapeutic efficacy of this particular approach. However, the system now appears to be practical, efficient, and technically robust. It now appears possible and necessary to evaluate whether this approach pro-

vides tangible benefits to either recent or long-standing head-injury patients.

This evaluation is presently in a pilot phase and there are as yet no results to describe. However, it may be of interest to briefly describe some aspects of the design of the study. To evaluate the effectiveness of rehabilitation on recent head-injury patients—those who enter the rehabilitation project shortly after trauma—it is necessary to use a matched untreated patient group to control for the natural recovery that occurs after cerebral trauma. In contrast the long-standing head-injury patients—those who enter the project more than 2 years after trauma—can serve as their own controls if a substantial pretreatment baseline is obtained. The serial assessments each consist of extensive neuropsychological, neurological, neuropsychiatric, and electrophysiological examinations. The electrophysiological examination includes the recording of both sensory and cognitive event-related potentials (ERPs). The work is continuing and future progress will be reported in this publication.

Establishment of a Central Nervous System Trauma Center_____

Lawrence F. Marshall

University of California/San Diego, La Jolla, CA 92093

Sponsor: *National Institutes of Health*

Purpose—The goals of this project are to determine the cause of the decline in mortality from head injury observed during the last 2 years in San Diego County and to develop a comprehensive program for spinal cord injury patients to include acute care and rehabilitation. We also will continue to develop a head injury remedi-

ation center for San Diego County, participate in the multicenter collaborative trial of high dose barbiturate therapy for uncontrolled intracranial pressure, and continue our clinical research on evoked responses and catecholamines in severely head-injured patients.

Establishment of a Central Nervous System Trauma Center_____

Kamran Tabbador

Yeshiva University, Bronx, NY 10461

Sponsor: *National Institutes of Health*

Progress—Data collection for a multicenter randomized controlled double blind clinical trial of barbiturate coma in intractable hypertension began in October, 1982. A study de-

signed to derive a profile of the traumatic spinal cord injured patient began in January, 1983. Neuropsychological and psychosocial data is being collected on mildly head-injured pa-

tients to study the cognitive impact and subsequent natural history of mild head injury in different populations. Studies being continued or completed include: an analysis of cognitive

outcome of severe and moderate head injury; analysis to characterize demographic and clinical features; and studies of the features influencing outcome.

Aphasia Rehabilitation Program

Robert Leedom, MSEE, MSCS and Andrew Jinks

Westinghouse Defense and Operations Division, c/o VME, Inc., Lutherville, MD 21093, and National Rehabilitation Hospital, Washington, DC 20422

Sponsor: *Volunteers for Medical Engineering, Inc.*

Purpose—A software program for the rehabilitation of a person with aphasia has been developed by the Volunteers for Medical Engineering, Inc. (VME), working with the Speech Pathology Department of the Johns Hopkins Good Samaritan Hospital. This program is designed to reinforce the memory of the client by giving, first, a question requiring a designated answer by filling in the blanks. If the person knows the answer, this is typed into the blanks and the maximum value is scored for that question. If one cannot recognize the needed word, then help can be had by pressing designated help keys whereupon the requested prompts (such as a high resolution graphic picture, or the beginning letter, are given on the screen or spoken by a speech synthesizer.) The system uses an Apple computer and Lis'ner 1000 speech synthesizer.

Progress—The software program has been written and is now being evaluated at the Johns Hopkins Good Samaritan Hospital and at the National Rehabilitation Hospital to determine: 1) how well it works for the clients; and 2) what improvements might be made to make it more effective.

Future Plans—We are starting to receive requests for the software from around the country and are preparing the documentation necessary for the users. The software developed to date has been done with spare-time volunteer effort. Proposals are being prepared requesting funding for this new effort and for the time to make requested improvements, so that timely releases can be made for the clients benefit.

Computer Acceptance of Maladaptive and Adaptive Aphasic Behaviors

Michael Collins, Ph.D.

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, Madison, WI 53705

Sponsor: *National Institute of Handicapped Research*

Purpose—This project will investigate computer strategies for recognizing perseveration and self-correction attempts by aphasic individuals, and will develop software routines both to interrupt perseveration and to facilitate self-correction. The behavioral tool for this project is

the Revised Token Test (McNeil and Prescott, 1978), a standard test in aphasia batteries, on which aphasic subjects are likely to display perseveration or self-correction tendencies. The programming for this project will be completed in 1986.

The Microcomputer as a Cognition Orthosis

N.L. Kirsch, Ph.D.; S.P. Levine, Ph.D.; L.A. Jaros, B.S.

Rehabilitation Engineering Division, Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center, Ann Arbor, MI 48109-0032

Sponsor: *Kenny Michigan Rehabilitation Foundation*

Purpose—The microcomputer has been used extensively as a tool for cognitive rehabilitation. Many microcomputer-based software packages for cognitive retraining of brain-injured individuals have been introduced. These programs attempt to remediate lost function.

Progress—Over the past 3 years we have developed a microcomputer-based system for compensatory intervention programs. This system is used to develop computerized “cognition orthoses” which are defined as “compensatory interventions stressing environmental modification and cuing for the completion of functional tasks.”

A programming language called COGORTH (from COGnition ORTHosis) has been developed to program instructional modules (IM's) which serve as task-guidance systems for cognitively impaired individuals. These IMs are intended to allow individuals with cognitive deficits to complete, independently, tasks they could not otherwise perform without assistance. An IM has been developed for training individuals to consistently respond to computer instructions and queries. The IM is for an artificial task (building a pyramid from colored blocks). The task has many levels ranging from building the pyramid with all blocks directly in front of the patient to requiring the patient to search for the various blocks in different rooms while encountering interruptions.

Preliminary Results—A clinical trial of a cognition orthosis has also been completed. The patient was a 28-year-old woman with a wide range of neurocognitive deficits, including severe memory impairments associated with an episode of herpes encephalitis. She required 24-hour supervision and guidance. A simple ABA design was used to assess whether or not the patient could benefit from a computerized cognition orthoses (i.e., an IM written in COGORTH). During the first phase of trials the patient made many errors while attempting to perform a simple cooking task using only written directions. During the second phase of trials the patient was able to perform error-free using computer-assisted guidance. Finally, during the third set of trials, the patient once again made many errors using only written directions.

Future Plans—Studies now in progress are investigating the efficacy of an IM written in COGORTH as an aid for the completion of vocational tasks. Future studies will also explore the utility of COGORTH as a tool for enhancing the acquisition (as opposed to merely the guided performance) of functional activities. Work also is progressing to install COGORTH on an intelligent mobile base. If successful, such robotic applications may permit the use of COGORTH as an interface for patients in environments such as nursing facilities, who might otherwise require continuous supervision.

COGORTH: Cognition Orthosis Programming Language

S.P. Levine, Ph.D.; N.L. Kirsch, Ph.D.; L.A. Jaros, B.S.

Rehabilitation Engineering Division, Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center, Ann Arbor, MI 48109-0032

Sponsor: *Kenny Michigan Rehabilitation Foundation*

Purpose—Patients who acquire diffuse and/or focal lesions of the brain often sustain dramatic and potentially debilitating changes

of cognitive functioning. These changes may be characterized by limitations of attention, orientation, memory functioning, reasoning, social

skills, and higher-order integrative functions. These may lead to severe disruptions of behavioral style, level of independence, interpersonal relationships, and vocational capabilities. A technique for assisting such patients to function independently, using a computerized cognition orthosis, has been developed. In demonstrations, this "orthosis" has been successful in guiding brain-injured patients through tasks they could not otherwise perform unaided. (See preceding report)

Progress—COGORTH, a specialized computer language, provides a highly structured environment for programming sequential messages. These messages can be used to assist patients who need guidance for the completion of complex activities. They can be in the form of text presented on a video display, or they can be in the form of an audio signal or a visual cue such as a flashing light. A COGORTH program (Instructional Module) can display directions to a patient at any level of specificity for any task which can be represented as a sequence of steps. It can present sequences of messages at any time of day specified by the programmer, and can repeat that sequence of messages at any interval.

COGORTH provides programming capabilities for Instructional Modules which can: 1) check a patient's performance for errors; 2) branch to error correction or "help" procedures when difficulties are encountered; 3) manage interruptions of a task when a higher-priority task must be complete; and 4) manage electri-

cal devices in a patient's environment. Instructional Modules (COGORTH programs) are written in standard text files. Although COGORTH is an interpreter, it permits the use of library files for the inclusion of user-defined functions and routines. It is envisioned that COGORTH will be used by health professionals having a wide range of programming skills. Careful consideration is, therefore, being given to balancing the power and complexity of the language against the need for simplicity.

The first versions of COGORTH were developed in the C programming language on the Apple II microcomputer. During the past year we have ported it to the IBM-PC, which has allowed significant enhancement of the language. The size limit of Instructional Modules has been greatly increased; execution speed also has improved.

Future Plans—A number of enhancements for the COGORTH programming language are planned: increased environmental-control capabilities (especially control of a telephone); increased graphics capabilities for displaying pictures and drawings within an Instructional Module; and the development of Instructional Module libraries for various tasks. These libraries are intended to provide basic Instructional Modules for a variety of tasks which can be modified to fit an individual user's needs. Long-range plans include the development of built-in COGORTH functions for control of a robotic base.

Pharmacological Therapies in Central Nervous System Injury

Alan I. Faden, M.D.

Veterans Administration Medical Center, San Francisco, CA 94121

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The major focus of this research is the development of novel pharmacological therapies for central nervous system (CNS) injury including stroke, brain trauma, and spinal cord injury. It is hypothesized that common pathophysiological mechanisms that underlie these various insults to the CNS in-

volve the release of endogenous factors (including endogenous opioids) leading to secondary changes in microcirculatory flow.

Progress—A number of new CNS injury models have been developed during the past year including: 1) a stroke model in rats produced by

occlusion of the middle cerebral artery; 2) a stroke-ischemia model in rabbits produced by reversible occlusion of the middle cerebral artery (MCA), using a specially-designed clip; 3) compressive brain injury in rats produced through an extradural balloon catheter; 4) ischemic lumbar spinal cord injury in rabbits, using an intra-arterial balloon catheter; and 5) traumatic lumbar spinal cord injury in rabbits, using a weight-drop method.

Progress—Much of the work during this first year has been devoted to setting up the models and laboratories, and in developing a number of important new outcome measures: somatosensory and spinal evoked responses; compressed spectral array analysis of the EEG; and magnetic resonance spectroscopy (proton and phosphorous). Our initial pharmacological studies have been devoted to an evaluation of opiate antagonists in the new models, including naloxone, TRH, and the kappa-selective antagonist WIN44,441-3. In these studies animals are randomly assigned to a treatment group. At present, data from the various models remains preliminary: the kappa-selective opiate antagonist WIN44,441-3 stereospecifically improved the computerized EEG after MCA occlusion in

rats and protected against the loss of high-energy phosphates after occlusion. In addition, opiate antagonists improved both survival and neurological recovery after traumatic spinal injury in rabbits.

Future Plans—We also plan to evaluate the effects of endogenous opioids on injury, in order to test the hypothesis that endogenous opioids are pathophysiological factors in CNS injury. Outcome measures, in addition to those listed above, will include neurological score, histopathology, changes in tissue levels of endogenous opioids, and potentially autoradiographic blood flow and metabolism. Since evaluation of each of these parameters in each of the models will take approximately 5 years, our initial focus will be devoted to ischemic and compressive brain injury and ischemic spinal injury. The early stress on brain injury models over spinal trauma models is due to the more advanced development of magnetic resonance spectroscopy, computerized electrophysiological measures, blood flow, and metabolism techniques in these models. However, development of magnetic resonance spectroscopy in spinal cord trauma will be an aim of later studies.

Comparing Rat Brain Pathways from Normal and Transplanted Motor Cortex_____

Frank R. Sharp, M.D.

Veterans Administration Medical Center, San Francisco, CA 94121

Sponsor: VA Rehabilitation Research and Development Service

Purpose—One of the brain areas commonly injured after stroke or trauma is the motor cortex. Motor cortex injury frequently results in lasting hemiparesis and/or expressive aphasia. Our long-term goal is to determine if motor cortex transplants could partially or wholly restore motor function lost due to motor cortex injury in experimental animals.

Future Plans—First, motor-sensory pathways to and from normal rat motor cortex will be mapped. Regions of increased ^{14}C -2DG uptake will be mapped during stimulation of hindlimb and rostral forelimb motor cortex. Afferents

and efferents of rat motor cortex will be described with wheatgerm agglutinin-horseradish peroxidase (WGA-HRP) and ^3H amino acids. Second, the motor-sensory pathways to and from rat fetal motor cortex transplants will be mapped. The patterns of 2DG uptake produced by electrically stimulating fetal transplants 1 to 16 weeks after transplantation will be compared to the 2DG uptake patterns during normal motor cortex stimulation. The afferents and efferents of the fetal motor cortex transplants will be mapped 1 to 16 weeks after transplantation with WGA-HRP and ^3H amino acids. Third, we will train rats to barpress with one

forelimb, and determine whether motor cortex injury affects the rats' ability to barpress acutely and chronically. If so, we will determine whether transplants reverse the motor deficits.

We have previously shown that fetal transplants survive in cavities in host brain motor cortex and have a nearly normal glucose meta-

bolic rate. The present experiments will determine whether the transplants form connections with host brain, whether transplant stimulation activates host brain and produces movements, and whether transplants improve behavioral motor deficits in lesioned adult rats.

Socio-Cultural Mechanisms of Rehabilitation in Old Age

Gaylene Becker

University of California, Aging Health Policy Center, San Francisco, CA 94143

Sponsor: *National Institutes of Health*

Purpose—Our objectives are: 1) to investigate the problematic issues suggested by the stroke rehabilitation literature—the influence of age on decisions about rehabilitation, practitioner/patient communication difficulties, lack of continuity in rehabilitation measures, minimal support to families, and health professionals' insufficient awareness of the influence of lifestyles on methods of coping with illness; 2) to address the major limitation of that literature—the lack of appropriate attention paid to process-in-stroke rehabilitation.

Future Plans—We will continue collecting data to test our specific research hypotheses. Patterns of intervention in the rehabilitation of stroke patients will be determined by three factors: 1) age of the patient; 2) physician attitudes toward rehabilitation that affect decision making; and 3) family members' perceived role

in the patient's rehabilitation and the nature and extent of their supportive efforts.

We plan to follow the rehabilitation process for 125 Mount Zion Hospital stroke patients and their significant family members for one year. To date, 48 patients are in the study. We plan to select the remaining 77 patients, conduct initial interviews, 3-month followup and 12-month followup interviews.

Qualitative analysis of first and 3-month followup interviews will continue: description of the range, content, and relationships among socio-cultural factors that influence the rehabilitation process. Quantitative analysis of first and 3-month followup interviews will begin and common descriptive statistics will be employed to explore a) means and medians for measures of central tendency; b) standard deviations for measures of dispersion; and c) relationships found among variables.

Remediation of Left-Sided Neglect and Interpersonal Communication Following Hemispheric Strokes

Laurence M. Binder and Lee Ann Golper

Oregon Health Sciences University, Portland, OR 97201

Sponsor: *National Institutes of Health*

Purpose—This Stroke Clinical Center Grant is a new application representing a continuation and extension of investigations initiated by a Comprehensive Stroke Center Contract, NINCDS. The major thrust of this contract is to assess the community (the State of Oregon in our case) profile of strokes, primarily demo-

graphic in nature; this contract mobilized a broad interest in our stroke patient, who represent the centerpiece of this grant application. Our investigations emphasize therapies focused upon stroke patients in three broad areas of importance in the continuum of the problem: 1) preventive therapy; 2) acute medical treat-

ments; and 3) rehabilitation intervention for higher cortical impairment.

Preventive therapies are designed to assess various risk and prognostic factors in stroke patients to develop better molecular handles on both acute therapy and prevention. Factors which may yield to better identification and therapy of risks are: mononuclear cell cholesterol ester hydrolase activity; glycosylated hemoglobin; cholesterol turnover in atheromatous plaques; and physicochemical bases for platelet

behavior in stroke. Acute medical treatments focus initially upon the potentially beneficial assessment of prostacyclin infusion. In addition, staged, sequential evaluation of aminophylline/barbiturate and vasopressors will be continued in a prospective, randomized fashion. Rehabilitative intervention for higher cortical impairment deals with neuropsychological and language impairments with compensatory learning strategies.

Precursors of Stroke Incidence and Prognosis

Philip A. Wolf

Boston University School of Medicine, Boston, MA 02188

Sponsor: National Institutes of Health

Purpose—It is proposed to extend the prospective findings of the Framingham Study on stroke to 30 years of followup, including the age groups 75-84 years, and to examine a number of possible precursors for which there has been too little followup. These include the role of: arrhythmias as determined by 1-hour ECG monitoring; echocardiographic findings of valvular and myocardial dysfunction; lipid profiles including LDL and HDL cholesterol; physical activity status; menopausal status; psychosocial factors including Type A personality; carotid bruit, Ecolyzer confirmed smoking histories, and glucose tolerance based on a glucose load, among others. Further studies of asymptomatic carotid bruits will be carried out by analyzing the continuous-wave Doppler signal for its direction, mean frequency, and frequency content, as they are found at selected moments in the cardiac cycle over the carotid arteries in the neck, and by analyzing phonoangiography of carotid bruits in an attempt to identify those bruits which are true precursors of stroke. A more accurate delineation of the type of stroke will be accomplished using CT scan information in addition to clinical findings. This should

permit better definition of the frequency of different types of stroke, and a more accurate determination of the epidemiologic features of each type.

The stroke, its precursors and disability will be pursued, focusing particularly on the elderly. Functional assessment of the patients' activities of daily living will be made at the time of stroke, and 3, 6, and 12 months later. Scores on recently standardized test scales of activities of daily living—feeding, dressing, grooming, bathing, etc; assessments of function in the home and in society; and the use of aids and appliances following stroke will be obtained by a rehabilitation nurse. These data will permit detailed evaluation of disability following stroke in a general population sample. An attempt will be made to devise a more powerful predictive stroke risk profile using those ingredients identified above as independent contributors to stroke incidence. The decline in mortality rates from stroke has accelerated in recent years. Secular trends in incidence by stroke type will require more cases occurring over time, and should be available as a by-product of this proposal.

Recovery from Aphasia in Stroke

Rita S. Berndt

University of Maryland Medical School, Baltimore, MD 21201

Sponsor: *National Institutes of Health*

Purpose—This project, by obtaining systematic evaluation of the course of recovery from aphasia in a population of stroke patients, has three specific goals. First, this project will seek extensive information on the demographic, neuroanatomical, medical, and neurolinguistic correlates of the recovery of specific language functions in aphasia. This information about prognostic factors can be used as a database for the development of on-line computer-assisted decision aids that would be of use to the neurologist in deciding questions of patient management.

Second, the study will evaluate the hypothesis that some language functions recover better than others. Experimental tests that allow relatively selective evaluation of distinct aspects of language comprehension (such as phoneme discrimination) and of speech production (such as syntactic complexity) will be administered. Scores obtained on these measures will be used to evaluate the possibility that there are different recovery rates for particular

aspects of gross language functions such as comprehension and production. In addition to their considerable theoretical importance, the results of such an evaluation would have significant implications for the design of therapies and development of communication aids for the aphasic patient.

Third, the study will furnish data for testing hypotheses concerning the functional components that underlie the major aphasic syndromes. Specific issues to be addressed include the incidence of linguistically-defined symptoms (e.g., agrammatism) within the classical syndromes (e.g., Broca's aphasia), and the extent to which the phenomenon of evolution of syndromes during recovery reflects substantive changes in language capacities. This third goal reflects an attempt to join the theories and methods developed in recent neurolinguistic studies of language impairment with the more traditional approach to the study of recovery from aphasia.

Rehabilitative Software for Head Trauma Victims

Sandra E. Hutchins

Emerson and Stern Associates, Del Mar, CA 92014

Sponsor *National Institutes of Health*

Purpose—Each year there are 70,000 new head trauma victims whose primary medical and long-term rehabilitation costs place tremendous financial burdens on their families. The need is great for low-cost rehabilitation tools that can be used in the home to supplement and reinforce therapy programs provided by rehabilitation professionals. Phase I of this effort will explore the viability of computer software implemented on inexpensive computers as an adjunct to professional therapy. Existing software will be altered to meet specifications prepared by the American Head Trauma Alliance (AHTA). Software will be provided both on cassette tape

and on cartridge to test ease of use of both forms. Alternate technologies for reprogramming cartridges will be evaluated.

A key element of the software design is the provision for modification by parents and therapists untrained in computing to tailor the programs to the needs and environments of individual head trauma victims. The resulting software and storage media will be tested by teams composed of head trauma victims, parents, and rehabilitation professionals. Guidelines for the development and use of such software will be prepared for dissemination by the AHTA.

Treatment of Affective Deficits in Stroke Rehabilitation

Wayne A. Gordon

New York University Medical Center, New York, NY 10016

Sponsor: *National Institutes of Health*

Purpose—Post-stroke affective disturbances are pervasive—i.e., they affect anywhere from 40 to 65 percent of stroke patients. The diagnosis and treatment of these disturbances in stroke patients is a major untreated problem facing the medical rehabilitation community. Traditional approaches to diagnosis which have relied exclusively on verbal self-report or nonverbal expressions of depression have not adequately addressed either the communication difficulties of aphasics or some of the other cognitive disturbances, such as aprosodia, minimization, and concrete thinking, which limit the cognitive capacities of stroke patients. Furthermore, the ef-

fectiveness of various approaches to treatment has not been systematically studied in this population at the present time.

The aims of this study are twofold: first, to validate a comprehensive diagnostic battery which permits an accurate examination of the affective disorders following stroke; and second, to evaluate the effectiveness of two approaches to treatment, anti-depressants and cognitive therapy, when administered singly or in combination. It is expected that greater accuracy in diagnosis and more aggressive treatment will significantly improve the quality of life of this subgroup of older Americans.

Community Study: Stroke Rehabilitation Using Volunteer Help

Sandra J. MacKay, R.N., Ph.D.

Veterans Administration Medical Center, White River Junction, VT 05001

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—This study is designed as a 3-year randomized clinical trial to determine whether aphasic stroke patients who receive volunteer visits three times per week for 1 year show any greater improvement in functional outcomes than those who do not receive such treatments. We oversampled, entering 95 patients into the study. The mean age of the test group was 75 versus 72 years in the comparison group. A two-tailed *t*-test indicates that these differences are not statistically significant.

Preliminary Results—More than 100 unpaid volunteers have been recruited to work with patients in the test group, and these volunteer visits have been enthusiastically received by patients, family members, and other caregivers both in private homes and nursing homes.

A statistical significance level of .05 was adopted for all analyses and groups were stratified by location. The means of the five major study variables for each group on entry into the

study indicate comparability of test and control group scores by home or nursing home. Scores on the Communicative Abilities in Daily Living for the test and control groups were 123 and 104 for patients at home and 51 and 36 for test and control group patients living in nursing homes.

Institutionalized patients in this study scored lower than institutionalized aphasic patients on whom this test was normed, which indicates greater impairment in this age group than might be expected. On PULSES Profile and Barthel's Index, there was greater functional impairment in the patients in nursing homes. Both the physical and psychosocial subscores of the Sickness Impact Profile also revealed greater impairment in nursing home patients. Thus, it was important to have stratified our randomization by location. The mortality rate in this study was higher than anticipated and further analyses are under way to examine this finding as it relates to treatment outcome.

Community Model: Rehabilitation of Older Adults with Brain Injuries

Sandra J. MacKay, R.N., Ph.D.

Veterans Administration Medical Center, White River Junction, VT 05001

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This randomized clinical trial will determine whether patients with acquired brain injuries due to stroke or trauma show any improvement in function as a result of receiving rehabilitation assistance provided by volunteers. Fifty-six patients have been entered into the study to date.

The performance of 100 patients will be assessed using multiple tools to measure functional outcome. The battery at 0, 6, and 12 months will consist of a neurological assessment; PULSES Profile, and Barthel's Index, field observations, and interviews by staff members

during which they will conduct the Rand Corporation's battery of physical, mental, and social health status measures, as well as their measures of general health perception. In addition, the Rosenberg Self-Esteem Scale will be used in conjunction with videotaped testing of the patient's performance in his own environment. This research is aimed at meeting the challenge of developing low-cost, quality rehabilitation services for an expanding elderly population in a manner which allows them to remain active participants in the communities where they live.

Efficacy of Computer-Assisted Rehabilitation

Gustave F. P. Sison, Jr., Ph.D.; Rodney D. Vanderploeg, Ph.D.; Herbert Goldman, Ph.D.

Veterans Administration Medical Center, Jefferson Barracks Division, St. Louis, MO 63125

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of the present study is to demonstrate in an experimentally controlled manner the efficacy of a computer-assisted rehabilitation program (in addition to traditional rehabilitation) in improving the cognitive deficits secondary to stroke. Subjects will consist of 60 inpatients referred from an intermediate medicine ward who are active rehabilitation candidates. Thirty patients with right hemisphere strokes and 30 with left hemisphere strokes will be randomly assigned to either an experimental or a control group. Thus there will be four groups of 15 patients each. All patients will receive extensive pre- and post-treatment assessment from neuropsychology, audiology and speech pathology, occupational therapy, and psychology. Patients in the experimental group will begin an 8-week computer retraining program (1 hour per day, 5 days per week), in addition to traditional rehabilitation therapies. Control subjects will receive tradi-

tional rehabilitation only, plus an attention and time control. All patients will receive post-treatment reassessment, and followup adaptive functioning assessment at 3 months.

Future Plans—Project beginning date was April 1, 1985. The study was originally designed to be completed within 2 years or by March 31, 1987. However, there has been an unavoidable delay in obtaining ADP equipment (i.e., the required computers and software rehabilitation programs necessary to begin the running of subjects and data collection). These ADP funds were released on January 15, 1986, computer and software orders were immediately placed, and the equipment was received on April 10, 1986. The initial subjects are now being recruited and run. However, the study will have to be extended, at least through Fiscal Year 1987, to meet the study objectives and answer the research questions.

The Impact of NMR on the Management of Brain Lesions

James Fletcher, M.D.

Veterans Administration Medical Center, St. Louis, MO 63125

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this study is to examine the effect of nuclear magnetic resonance (NMR) on the length of stay, hospital course, and diagnostic and therapeutic outcome of patients admitted for evaluation of possible intracerebral neoplasm or cerebrovascular abnormality. The design of this study involves a retrospective medical chart review covering two time periods. These periods will produce three comparison groups: 1) patients undergoing evaluation when only CT is available (the CT 1983 group); 2) patients evaluated when NMR is available and who undergo NMR imaging; and 3) patients evaluated when NMR is available but receive no NMR imaging. Analysis of variance and cost-benefit analysis will be performed to evaluate the comparison groups.

Progress—To date, approximately 75 percent of all potentially eligible charts have been located and abstracted. Half of these have been recoded

and the data entered onto magnetic tape. By July 31, 1986, the remaining available charts will have been abstracted, recoded, and entered onto tape. Following this task, data analysis will begin and will continue through September 1986. This is in accordance with the original project management plan. No major deviations from the original proposal have occurred or are expected with respect to workscope, budget, or schedule. Results are not yet available.

Future Plans—The results of this study are expected to provide empirical evidence of the impact, if any, of NMR on the clinical course of patients undergoing evaluation for suspected brain lesions. These data may be utilized by decision makers within the VA system and elsewhere in determining the efficacy and cost benefits of NMRs and may provide additional input into future NMR implementation decisions.

Evaluation of Family Stroke Education

Ron L. Evans, M.S.W.

Seattle Veterans Administration Medical Center, Seattle, WA 98108

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Failure in rehabilitation after stroke is often caused by lack of family education, but what educational content is essential to include in routine treatment for families of stroke patients has been difficult to determine. The effects of a structured education protocol is being measured with a Stroke Care Information Test, Family Assessment Device, and ratings of treatment adherence and family resources. About 160 hospitalized stroke patients will be selected for inclusion of a family member in scheduled stroke care instruction versus placement in a control group receiving no formal involvement with health care staff. It may be possible to improve adherence to a rehabilitation program by working with the family in areas found to be

related to informational needs.

Experimental subjects are expected to make significant increases in knowledge about the implications of stroke. Provision of reliable information about stroke may increase the effectiveness of rehabilitation efforts, reduce rehospitalization rates, allow persons to avoid extended convalescence, or improve compliance with rehabilitation principles.

Results—The pilot study findings are promising and were presented at the 1986 Dinsdale International Conference on Rehabilitation in Ottawa. Caregivers of 60 stroke patients were assessed 4 months after patient discharge from a stroke care unit. Areas of family interaction

which were significantly correlated with ratings of treatment compliance included: problem solving, communication, and affective involvement. Significant correlations were not observed for emotional response of the family, social role assignments, or behavior control. Better functioning families were consistently rated high on treatment compliance. Findings suggest that families with specific dysfunctional interactions may not comply with treatment

recommendations for home care after stroke.

Using a process of minimization to control for intervening variables, stroke patients are continuing to be selected and assigned to treatment or control groups to evaluate the effects of family education on stroke outcome. A paradigm to predict stroke outcome based on family instruction is being developed and two treatments, counseling and classroom instruction, are being compared.

Microwave Hyperthermia

Daniel Buck, B.S.E.E., M.S.E.E., M.S., and Herman Rossman, B.S.M.E.

Westinghouse Defense and Operations Division (D&OD), Baltimore, MD 21203

Sponsor: *Volunteers for Medical Engineering, Inc.*

Progress—This study is being carried out under the direction of Dr. Michael Saloman, director of the neurosurgery department of the University of Maryland Hospital. A major part of the study is being done by the Volunteers for Medical Engineering, Inc. (VME) The engineers and technicians in this organization are presently donating their time and talents to the effort and are working in their basements or during their lunchtimes at Westinghouse Aerospace to accomplish their goals. Dan Buck, a Senior Advisory Engineer, has taken a network analyzer and ancillary equipment donated by Westinghouse to the VME, and has set up a lab so that he and his colleagues can carry out their investigations. Herman Rossman, another engineer specializing in thermal analysis, is designing a tissue simulator which includes an aqueous medium in an enclosure, and is formulating the contained interstitial material of the enclosure so that the microwave radiators can be used in the container to irradiate the simulated brain tissue with a dielectric constant of 50. The premise is that most of the work done to develop the microwave radiating element and the radiometer can be done on the simulated brain tissue and that the need for experimentation with animals can be reduced or eliminated. This is especially important regarding brain tumors because canine and feline brains are too small to properly simulate human brain. The model will also simulate the blood flow of

healthy tissue as well as that of the tumor. Analysis of the conditions at the interface of the tumor and the healthy brain tissue show good correlation with data from several other sources, giving credibility to the analytical approach and the assumptions that the blood flow in the tumor is poor compared to that of healthy tissue.

Preliminary Results—Preliminary tests on a novel "twin lead" antenna concept show microwave "end fire" penetration into phantom tissue greater than 1 cm for frequencies between 9.5 MHz and 1.8 GHz. Tests show bandwidths up to 200 MHz, which enables one to use radiometry for temperature measurements. This requires no extra invasive probes.

Three electronics technicians have been working to fabricate the microwave radiometers needed to test the various configurations. Several of these have been tested and the test results show that the radiation pattern can be controlled and the size of the invasive probe elements can be minaturized to be accommodated by the tubes inserted in the site of the tumor. A meeting with Dr. Saloman in June, 1986 revealed that radiometry capabilities to start temperature measurements were urgently needed. We also received dielectric constant 50 tubes from Trans-Tech, Adamstown, MD, (a gift to VME) to start work on a better impedance match to the brain tissue.

Future Plans—Several proposals are being prepared to seek funding for these study efforts in order to arrive more quickly at a radiating element that will deliver a controlled radiation

pattern while monitoring the temperature of the irradiated tumor so that only the tumor is elevated to the destruction temperature.

A Prosthesis for Writing in Aphasia

Jason W. Brown; Cynthia Blum; Barbara Leader; Cynthia Moreno

New York University Medical Center and Manhattan Veterans Administration Hospital, New York, NY 10010

Sponsor: *Institute for Research in Behavioral Neuroscience*

Purpose—A case of severe nonfluent aphasia is described in which therapy with a writing prosthesis over a 6-month period resulted in a dramatic improvement in writing ability with the hemiplegic right limb in spite of minimal improvement in oral production. Convention and prosthesis therapy for writing with the left hand resulted in only marginal change. Hemiplegic writing with the aid of a prosthesis may be the most effective means of communication in severe aphasia.

Severe aphasics with right hemiplegia are often, with the aid of a prosthesis, able to write words to dictation with their hemiplegic limb though agraphic with the intact left hand. In global aphasics, hemiplegic writing is often the best linguistic performance and is superior to writing ability in many less severe aphasics without hemiparesis. This finding suggests that the retraining of writing in hemiplegic aphasics should be directed to the use of a right arm prosthesis rather than practice with the left hand. This paper reports the results of prosthesis training with a severe nonfluent aphasic.

Progress—A 58 year-old right-handed man developed a left CVA and right hemiparesis in December 1981. There was excellent recovery of speech and movement. A later CT scan demonstrated dilation of the left post-central sulcus consistent with infarct. One month later he developed another left CVA with persistent severe aphasia and denser right hemiplegia. On neurological examination he was alert and well-oriented, with spastic right hemiplegia, probable right visual field defect, and intact sensation. He walked with a cane. Mild bilateral conductive hearing loss was present. An EEG

showed left temporoparietal slowing.

Repeat CT scan demonstrated an extensive infarct involving frontal and parietal opercula and insula, sparing basal ganglia and thalamus. The infarct extended posteriorly to a supramarginal and angular gyri. Testing revealed marked nonfluent aphasia with moderate comprehension impairment. Spontaneous speech consisted of stereotyped perseverative single words and vowel sounds with severe oral apraxia. Answers to yes/no questions were unreliable; some monosyllabic words were repeated. On the Boston Diagnostic Aphasia Examination, auditory comprehension was spared for body parts and commands, and was poor for picture identification of auditory stimuli. Severe deficits were present on naming, oral reading, and repetition. Reading comprehension was poor for symbol discrimination, word recognition, and word-to-picture matching, but comprehension of sentences and paragraphs was rated as fair on testing.

Reevaluation 9 months post-onset showed improvement in comprehension and writing and little change in verbal skills. The patient was considered to have stabilized in therapy and a modified course of Melodic Intonation Therapy (M.I.T.) was initiated. With M.I.T., the patient experienced success only in the therapy setting and then only with cues (usually phonemic). There was no carryover to spontaneous use in therapy or at home. The patient began using the writing prosthesis 2 years post-onset. Initially, motor training involved tracing geometric shapes and a specially designed block letter alphabet in which each letter could be formed using one continuous stroke. For the first 2 months, the patient received two half-

hour sessions per week, which were later extended to 1 hour twice a week. To aid in the legibility of the letters and to constrain arm movements, the patient was required to insert individual letters within the squares of a grid. Fine motor control was not always possible, and the patient often strayed beyond the bounds of the outline.

Once the alphabet was mastered and the patient was comfortable using the device, a systematic approach to writing was initiated. Targets in writing progressed from single nouns and verbs to two-word productions (adjective + noun; noun + verb; verb + object) to phrase-length strings incorporating varied syntactic structures. A picture was shown, and the patient was asked to respond to various questions, such as: "Who is this?" or "What is going on?" The sentence length was increased to noun + verb + object, and then nouns were expanded to noun phrases (article + noun, adjective + noun).

Spontaneous writing (picture description) with the prosthesis tended to be agrammatic. In order to elicit correct spelling and syntax, dashed lines representing letters in the words of a simple descriptive sentence were entered into the grid for each picture stimulus. The patient was informed that he was to write a description of the picture using the dashes as cues, and to respond to questions as above. He was never specifically told to use any functors. He seemed to realize when functors were required, and either filled them in spontaneously or self-corrected after inserting content words. With this approach, he was able to produce sentences of astonishing complexity and good syntax given the severe nonfluency of speech and the relative agraphia with the intact left hand.

The training procedure for the right arm with the prosthesis was duplicated for the left arm, which was trained and tested under similar conditions using the same stimuli on different days. This permitted a direct comparison of left- and right-handed writing. Writing was analyzed as to orthography (legibility), spelling, relevance to stimuli, total word count, and types of grammatical forms. A consistent and

profound right arm superiority was present on all parameters including constrained versus unconstrained conditions. Left-hand writing, even with maximum structure, consisted of noun listings, odd letter strings, and unidentifiable sequences.

Preliminary Results—A patient with severe nonfluent aphasia received therapy with a writing prosthesis 2 years post-onset, and showed dramatic improvement in oral production. Conventional and prosthesis therapy for writing with the left hand resulted in only marginal improvement. These findings indicate that, in contrast to the usual approach, the treatment of writing impairment in hemiplegic aphasics should, in many cases, be directed at the hemiplegic limb rather than the "intact" left hand.

The use of a grid and dash format to constrain limb movement and direct attention to syntax made it possible to elicit sentences on picture description which were impressive in their syntactic structure given the degree of nonfluency, the extensive left frontoparietal CT lesion, and the dense left hand agraphia. This contrasts with agrammatic written productions to questions and picture descriptions without the constraints of the "dash" format, and supports the view of retained competence in agrammatism.

Studies of agrammatism show parallel syntactic deficits in comprehension and production, though few studies have tested subjects in multiple performance modalities, especially in writing. The results with our patient show that, with the appropriate method, considerable syntactic knowledge can be accessed in a severe motor aphasic.

The ability of this patient to write sentences with the hemiplegic limb, and previous demonstrations of writing to dictation in global aphasics, indicate that mental language is available to an extent not predicted by the production pattern. Studies of inner speech in aphasia, from early work on the Proust-Lichtheim maneuver (counting syllables in words) to the "tip-of-the-tongue" phenomenon, have not documented a dissociation between inner speech and speech production. Our cases are of

both practical and theoretical interest in demonstrating that it is possible to tap the inner mental life of the severe aphasic.

In our initial report we suggested that submerged levels in language representation might be accessed through the use of an older axial and proximal motor system. Specifically, the disruption of a "surface" level in language and motility permits access to earlier processing stages in both systems. This case extends the

findings of hemiplegic writing from global aphasia to severe anterior or "mixed anterior" aphasia and demonstrates that a program of therapy using the writing prosthesis can result in dramatic gains in writing out of proportion to other aspects of language production. This finding establishes training in hemiplegic writing as an adjunct to aphasia therapy, and provides a method for the exploration of language capacity in patients with severe aphasia.

Device Evaluation for Cognitively and Motor-Impaired People _____

Cheryl Goodenough-Trepagnier, Ph.D. and Michael J. Rosen, Ph.D

New England Medical Center Hospitals, Boston, MA 02111 and Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *National Institute of Handicapped Research*

Purpose—The Tufts-MIT Prescription Guide, described in an accompanying report, has been developed to evaluate the suitability of alphabet-based devices for motor-disabled clients whose cognitive impairment is not severe. The purpose of this project is to develop additional client evaluations and devices evaluation items as needed in order to provide useful guidance in the selection of a most appropriate device for a client who may not, or not yet, be capable of functional spelling.

Progress—To date, work has focused on improving the existing system in order to make it

more easily used by and more informative to clinicians without requiring them to have specific knowledge of Lotus, programming, or the particular structure of the system. Part of our evaluation of client needs has been restructured using an expert system shell. Evaluation with clinicians is taking place to assess the usefulness of that structure as opposed to the existing structure, which is an adaptation of Lotus 1-2-3 software. Review of cognitive assessment materials for use with motor-disabled and cognitively-impaired individuals, or young people is now in progress.

XV. Geriatrics

Memory Remediation in Older Adults: A Computerized Interactive System

Anderson Dodd Smith; Donald D. Wall; Clarence M. Rogers

Veterans Administration Medical Center, Decatur, GA 30033

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The objective of the current project is to develop an interactive computerized memory task that allows patients to practice specific everyday memory skills. Specific memory skills will be identified for pilot use in two ways. First, memory questionnaires will be examined from normative studies in the literature. Second, skills will be identified through interviews and surveys of VA patients and staff working with older adults on a daily basis. Programs will be developed using the MUMPS language which is designed to train and practice the memory skills through interaction with the computer terminal. The interactive system will then be evaluated, both in terms of its validity of memory improvement and in terms of user compatability (user response).

Memory assessment for older adults in clinical settings often involves global assessment

batteries (e.g., Wechsler Memory Scale), tests derived from the psychometric perspective which often have limited application when remediation is desired. The current project plans to use “everyday” memories, thereby addressing the specific memory problems as they are identified by either the clinician or the patient.

The project team consists of a cognitive psychologist who has extensive research experience with memory performance in older adults, a VA clinician with experience with geriatric medicine and the VA population, and a mathematician with expertise in computer systems design and programming.

Future Plans—The research team will conduct the necessary pilot work to test feasibility for the project.

Nutrition and Health in the Aging Veteran Population

Robert A. Pearlman, M.D., M.P.H., and Bonnie Worthington-Roberts, Ph.D.

Seattle Veterans Administration Medical Center, Geriatric Research Education and Clinical Center 98108, and University of Washington, Seattle, WA 98195

Sponsor: *Health Services Research and Development Service, Veterans Administration Medical Center Seattle*

Purpose—The overall goal of this study is to explore relationships between nutritional status and health in ambulatory geriatric patients. Objectives are to: 1) describe the nutritional status of an elderly, ambulatory veteran population; 2) identify and measure factors associated with inadequate dietary intake, and describe the relationship between these identified correlates of dietary intake and measurable, nutritional status; 3) describe the relationship between nutrition and health status; and 4) develop a statistical model (nutritional prognostica-

tion index) for identifying older persons at additional risk for unscheduled hospital utilization and prolonged hospitalization.

Physiological and social concomitants of advancing age increase the risks of consuming an inadequate diet and developing nutritional deficiencies. Nutritional status may affect health status and utilization of health care facilities; on the other hand, physical, functional, or emotional aspects of health may affect nutritional status. For these reasons, longitudinal assessments of physical, medical, social, and nutri-

tional characteristics will be made.

Progress—Instruments have been pretested and finalized to ensure patient comprehension and acceptability, as well as administrative feasibility. Approximately 10 percent of the patients have been seen for the entry evaluation.

Future Plans—The population will include 275 ambulatory veterans who are 65 years of age and older and who currently use, or are eligible for care at, VA facilities, and whose medical records do not indicate diseases known to cause nutritional debilitation. Nutritional status will be compared with social, environmental, and gerontological variables, and with several measures of health. Changes will be monitored in each variable and in health care utilization over the ensuing 2 years. Patients will be randomly selected, then screened for eligibility. Upon inclusion, patients are interviewed about social and environmental factors that may influence dietary intake; attitudes and knowledge about nutrition; health status (physical, psycho-

logical, and functional, and utilization of health care services); dietary intake; and daily activities. Physical examination includes anthropometrics (triceps, biceps, subscapular, and suprailiac skin folds; chest, waist, hip circumferences; tibia and total arm lengths; and body mass index), screens for sensory and motor deficiencies, and a gait assessment. Laboratory examination includes selected measures of protein status (lymphocyte count, transferrin, albumin, creatinine/height index); vitamins (B₁, B₆, C, folate, D); and minerals (calcium, zinc, selenium, potassium, copper, magnesium). Cellular immunity is measured with mumps, candida, and trichophyton skin tests. Home visits assess potential environmental determinants of nutritional status and supplement the interview. Evaluations will be repeated at 1 and 2 year intervals following entry into the study, and 3 months after each hospitalization. Age-matched comparisons will be made between this population and the Health and Nutrition Examination Survey II.

Evaluation of Independent Living Services for the Chronically Ill Elderly

Daniel E. Rodell, Ph.D., and T. Michael Kashner, Ph.D

John L. McClellan Memorial Veterans Hospital, North Little Rock, AR 72114, and Health Science Center, University of Oklahoma, Oklahoma City, OK 73107

Sponsor: Health Services Research and Development Service

Purpose—The objective of the study is to evaluate the effectiveness of an Independent Living Program (ILP) model that provides in-home services to chronically ill, previously hospitalized patients from the Geriatric Research, Education and Clinical Center (GRECC) at Little Rock VA Medical Center. Specifically, we will determine if ILP 1) enhances the quality of long-term care; 2) reduces the likelihood that the patient will become institutionalized; and 3) is a more cost-effective substitute for traditional modes of long-term care. Traditional modes of long-term care are characterized by extensive utilization of inpatient care and, for those community-based patients, frequent episodic trips to VA outpatient facilities.

It is hypothesized that patients who receive

ILP services will experience: 1) improved functioning on activities and instrumental activities of daily living; 2) the development of stronger social support systems; and 3) the procurement or adaptation of the physical environment that best addresses the strengths and limitations of the individual when compared to control patients who do not receive these services. Furthermore, patients receiving ILP services will utilize more community (non-VA) services than comparable controls resulting in fewer and shorter admissions to hospitals and nursing homes, fewer VA (non-ILP) outpatient visits and hospital clinic appointments, and more days at home. The realization of the patient's maximum potential for independent living as well as an increased reliance on community

(non-VA) services affected by ILP intervention should produce a cost-savings to the VA that makes the provision of this service both feasible and affordable using the experience of equivalent controls as a benchmark.

Progress—As of June 1986, 47 patients have been enrolled.

Future Plans—Over a 2-year period, a study population of 360 consenting patients discharged to their own homes from the Geriatric Service at the Little Rock VAMC will be randomly assigned to an experimental (ILP) or a control (non-ILP) group. All clients will continue to receive Geriatric Service intervention. Prior to randomization, data reflecting the general status of the patient at admission to the Geriatric Service and prior to the onset of the

acute condition precipitating admission will be gathered. Status following randomization will be assessed at quarterly intervals following discharge from the inpatient Geriatric Service for a 1-year period. Status is defined as: 1) the functional capacity of the client to engage in activities and instrumental activities of daily living; 2) the size, nature, and capability of the client's social support system; and 3) the living arrangement or setting.

Information on the utilization of other (non-ILP) VA and selected community (non-VA) health care services during the followup period will be collected for all clients. The total cost to the VA for health and income benefits received will be calculated as will the cost of community services charged to the client, third-party carriers, or government intermediaries. Target date for completion of the study is June 1989.

Adjustment and Rehabilitation of Chronic Illness Among Older Americans

Carol J. Dye, Ph.D.

Veterans Administration Medical Center, St. Louis, MO 63125

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Previous research in the benefits of exercise rehabilitation programs for COPD patients has shown that not only do physical functions improve but there may also be improvements in psychological factors such as permeability and adjustment. This study will take that research one step further and explore the benefits from the components of the program, i.e., exercise and nonexercise components, in relation to the benefits gained from the total program. The focus will be to measure changes or psychological and emotional adjustments to variables compared to cognitive functions for these components of the exercise program.

Progress—The subjects for this study are 160 aged veterans. These subjects comprise four groups of 40 each, matched for marital status, education, age, and socioeconomic status.

One group of 40 veterans participates in the total exercise program as it is presently offered at the medical center. The program includes exercise and nonexercise components.

Another group of 40 veterans participates only in the exercise portions of the program, the third group only in the nonexercise portions of the program. The fourth group is a normally aging, community-based group of veterans without COPD.

The study is complete and the data are being analyzed.

Future Plans—All groups will be measured with adjustment and cognitive measures at time intervals matching entrance into the program, 6 weeks later at the end of the in-hospital portion of the program and 3 months after discharge. Measures include anxiety, depression, feelings of control, intellectual function, learning, and memory. It is proposed to determine how the various components of the program contribute to improvement in psychological functioning, how pulmonary patients differ from normally aging veterans in psychological function, and how close to normal function exercise rehabilitation can bring veterans who

are COPD patients.

The Social and Medical Effects of Amputation on Elderly Veterans

Robert C. Yang, M.D., and P.S. King

Veterans Administration Medical Center, Portland, OR 97207

Sponsor: VA Rehabilitation Research and Development Service

Purpose—During 1978, a study of the social and medical effects of amputation was conducted jointly by Portland VA Medical Center and Portland State University. The information gained from this study strongly suggests the need for a followup investigation.

This research project will collect new information on the sample interviewed in 1978, and interviews will also be conducted on the 75 amputees who now fit the criteria of the study. The project will be coordinated between Portland VA Medical Center and the Portland State University Center for Public Health Studies.

Methodology to be used will: 1) update the original 1978 study; 2) survey a new sample of

elderly veteran amputees and their primary care givers; 3) complete a clinical review of patient information on elderly veteran amputees; and 4) complete a report of findings.

The information to be collected includes the following: 1) a profile of the individual's medical status; 2) length of time for the amputation stump to heal; 3) time involved in rehabilitation; 4) prior vascular surgery; 5) complication of surgery; 6) relevant discharge information; 7) length of survival of leg; 8) number of hospitalizations as a result of amputation; and 9) revisions to and replacements of the prosthetic device.

Discharged Elderly Patients from the Memphis VA Medical Center Nursing Home Care Unit (NHCU): A Followup Study

Frederick Blow, Ph.D.; L. Barnes; and M. Ochs

Veterans Administration Medical Center, Memphis, TN 38104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Nursing home care focusing on rehabilitation, and the promotion of self-care has been essential in returning selected patients to their usual living arrangements following acute hospitalization. To date, however, there have been few follow-up studies on discharged elderly patients after comprehensive rehabilitation. The primary purpose of this study is to assess post-discharge mortality and to determine current placement of patients discharged from the Memphis VAMC Nursing Home Care Unit (NHCU).

Progress—A review of the inpatient data available on all patients discharged from the NHCU prior to April 20, 1985, was completed as part of the first phase of this two-phase project.

Four hundred seventy patients, 55 years

and older, whose primary diagnoses were not cancer-related, were identified. Preliminary screening showed that 352 patients had been discharged to their usual living arrangements. Patient records were reviewed to locate current phone numbers and identify patients who had died since discharge. Fifty deaths were subsequently recorded, completing phase one of this project. The second phase of this followup study has begun. Postdischarge data is currently being collected by phone interview. Two hundred fifty-five patients with phone numbers available through file and directory information have been identified. To date, 61 of these individuals have been contacted and postdischarge data have been collected. Fifty of these individuals have remained in their discharge location, three have died, and eight have been ad-

mitted to extended care facilities.

A written questionnaire identical to the one used in the phone interview is currently being developed. This written questionnaire

will be mailed to individuals who do not have phones to ensure that all patients who have been discharged to their usual living arrangements may be contacted.

Impact of a Geriatric Assessment and Rehabilitation Unit on Subsequent Health Care Expenditures

William B. Applegate, M.D., and Frederick Blow, Ph.D.
Veterans Administration Medical Center, Memphis, TN 38104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This study will consist of a randomized controlled trial in which frail, functionally impaired elderly hospitalized patients in danger of nursing home placement will be randomized to a geriatric assessment and rehabilitation unit (GARU) or to usual sources of care in the community. The primary objective of the project is to determine if specialized care on a GARU for high-risk elderly patients can reduce health expenditures by reducing subsequent rates of nursing home placement and repeat hospitalization.

The GARU to be studied is a 10-bed unit which has been in operation for 5 years (169 admissions last year, average length of stay 21 days) at the Regional Rehabilitation Center of the Baptist Memorial Hospital, Memphis, Tennessee. This GARU is one of the few such units available for study in the private sector.

Geriatric assessment and rehabilitation units offer specialized multidisciplinary assessment of patient problems in multiple domains. These include medical problems (medication toxicity, incontinence, transient confusion, immobility, weakness, malnutrition, gait disorders), emotional problems (affective disorders),

functional problems (need for prostheses and appliances, activities of daily living, instrumental activities of daily living), and social problems (arrangements for appropriate level of care, including home support and family counseling).

Patient function will be evaluated with self-assessment measures and through the observations of an assessment team not involved with the patient's care. The analysis will evaluate the impact of the GARU on the intervention group by analyzing differences in these outcomes between the two groups (intervention and control groups). If a GARU can be shown to have a positive impact on health care expenditures or rates of nursing home placement, then reimbursement policies may be changed in order to promote development of such units.

Progress—Beginning July 1985, we field-tested data collection instruments and began patient enrollment July 22, 1985. To date, we have randomized 58 patients followed up with forty five 6-week home visits and five 6-month home visits. At the present rate, we expect the enrollment phase to continue for the next 12 months.

Low Vision Rehabilitation and Age-Related Maculopathy Syndrome

Joan D. Stelmack and J. Trimble
Veterans Administration Medical Center, Hines, IL 60141

Sponsor: VA Rehabilitation Research and Development Service

Purpose—For elderly persons who are vision impaired, low vision services are a means for learning to utilize their remaining vision and increase their independence. These services

help to reduce the economic burden on society and help us to fulfill our obligations to the elderly. The goal of the proposed project is to test a protocol for evaluating low vision treatment

of age-related maculopathy syndrome (ARMS). The correlation between the clinical tests used in evaluation and the functional performance of ARMS patients using low vision aids will be measured.

The research plan is to perform clinical evaluations on 30 legally blind geriatric patients with ARMS, to train these patients to use their remaining vision, and to assess performance with one of two low vision aids, either a headborne reading aid or a closed circuit tele-

vision (CCTV). Performance will be evaluated by measuring reading speed and reading duration. Clinical evaluation will include tests of visual acuity, refraction, evaluation of internal and external ocular health, fundus photograph, measurement of visual fields with Goldman perimeter, and measurement of contrast sensitivity using vertical sine wave gratings displayed on a cathode ray tube (Tektronix 606A, P31 phosphor) under computer control.

Bicycle Ergometer With Computer-Controlled Resistance and Video Display_____

Arthur Koblasz, Ph.D.; R. DeAndrade; D. Bholet

Veterans Administration Medical Center, Decatur, GA 30033

Sponsor: VA Rehabilitation Research and Development Service

Purpose—We originally proposed to design and construct a bicycle ergometer specifically for geriatric patients. Bicycle ergometers are relatively inexpensive and do not require a large amount of space. However, they have little heuristic value and are not very appealing to elderly patients. We proposed to invent a bicycle ergometer with the following features: 1) footpedal resistance generated by a clutch mechanism and controlled by a microcomputer; 2) pedal resistance correlated with a video game depicting a bicycle travelling along a contour; and 3) game protocol varied depending on the patient's heart rate. We expected that the proposed exercise device would encourage geriatric patients to exercise and thereby promote physical conditioning.

Progress—We first designed and built a steel bike frame suitable for geriatric riders. The frame includes a high-back cushioned seat and a differential gear assembly which provides a 16:1 ratio. The gear assembly mates up to a magnetic particle clutch with a continuous torque resistance of 0 to 180 inch-pounds. We were able to demonstrate IBM-PC control of the clutch using a D/A interface. However, it is apparent that the bike frame is too bulky and the gears are far too noisy. At this time, we have halted the project until we are able to identify some source of support which will permit us to make radical changes in the frame design and the gear assembly.

Geriatric Dentistry Academic Award: Tufts University_____

Hilde H. Tillman

Tufts University, Boston, MA 02111

Sponsor: National Institutes of Health

Purpose—It is the specific aim of this program to create a Division of Geriatric Dentistry at Tufts University School of Dental Medicine and to develop a comprehensive interdisciplinary didactic and clinical curriculum. It will be allied with Forsyth Dental Center, the developing Medical Geriatric program, the Human Nutri-

tion Research Center on Aging, the Aging Activities of the Department of Psychiatry and the Veterinary School. This division will present the complexity of aging to undergraduate dental students, graduate dental students, dentists, dental hygienists, and staff.

The interdisciplinary faculty will include

Gerontology, Physical Medicine and Rehabilitation, Nutrition, and Psychiatry. The allied professionals include Social Service, Occupational Therapy, Physical Therapy, and Speech and Hearing.

The geriatric curriculum will be interwoven throughout the 4 years of training. The program includes a special lecture series. The second semester of the second year will include required seminars and clinical assignments in the four-chair geriatric area and the Chelsea Soldier's Home. The program outreach activities include the Hebrew Rehabilitation Center,

community residencies, nursing homes, and bedside dentistry with portable equipment.

Research activities are planned in all phases of Gerontology and Geriatric Dentistry, as well as a strong continuing education program for dentists, postdoctoral students, and staff. Particular emphasis is placed on faculty development in Gerontology and Geriatric Dentistry. The program evaluation will insure our long-term objectives: to train dentists competent in rendering total patient care to this growing segment of our society.

Geriatric Medicine Academic Award: University of Chicago

Leif Sorensen

University of Chicago, Chicago, IL 60637

Sponsor: *National Institutes of Health*

Progress—The Pritzker School of Medicine, University of Chicago, has designated Dr. Leif B. Sorensen, Professor of Medicine, as its candidate for the Geriatric Medicine Academic Award. A program for development and continuous strengthening of teaching and research in gerontology and geriatric medicine is proposed, with the following objectives: 1) to expose all students to gerontology/geriatrics by incorporating topics on aging into the required courses of the preclinical curriculum; 2) to develop an elective course entitled "Introduction to Geriatrics" in the sophomore year; 3) to incorporate segments of geriatric medicine into the major clinical clerkships; 4) to develop a 2-month elective for senior students entitled "Comprehensive Geriatrics"; 5) to establish a Geriatric Outpatient Clinic and an Inpatient Consultation Service as educational and clinical care facili-

ties; 6) to establish an 'Office of Geriatrics' as a center for administrative and educational activities; 7) to provide house staff with opportunities for training in geriatric medicine in the ambulatory setting; 8) to offer a 2-year fellowship training program aimed at promoting careers in academic geriatric medicine; 9) to conduct Grand Rounds and CME courses to increase the awareness of faculty and practitioners to the unique medical and psychosocial problems of the elderly; 10) to foster the development of research programs on aging; 11) to develop promising young faculty interested in committing their careers to geriatrics; 12) to provide an opportunity for the awardee to acquire additional skills with a view toward enriching the curriculum; 13) to facilitate interdepartmental and multidisciplinary teaching and research in the field of aging.

Geriatric Medicine Academic Award: University of North Carolina/Chapel Hill

Paul Beck

University of North Carolina at Chapel Hill, Chapel Hill, NC 27514

Sponsor: *National Institutes of Health*

Purpose—The long-term objective of this Geriatric Medicine Academic Award application is to develop a superior curriculum in aging and

geriatric medicine at the University of North Carolina, Chapel Hill, School of Medicine that will stimulate medical students, house officers,

faculty, and practicing physicians to provide high quality medical care to the elderly and also attract outstanding students and house officers to research in the processes of aging and diseases of the elderly. The specific aims and methods of this curriculum proposal are: 1) to update the standard required curriculum for medical students to insure that they obtain the knowledge of gerontology and skills of communication and physical examination necessary for working with elderly patients;. 2) to reinforce the principles of gerontology and geriatric care through clinical problem-solving experiences with case exercises and geriatric patients. Resident's reports, case conferences, medical grand rounds, and interdisciplinary (medical,

nursing, social work, occupational therapy) team consultations will be used as teaching settings; 3) to develop model care sites (at the University teaching hospital, Area Health Education Centers [AHEC's], retirement communities, nursing homes) where geriatric care will be provided in a manner which is conducive to learning; 4) to enhance the competence of the faculty in dealing with the problems of aging, particularly to encourage acquisition of knowledge about geriatric topics that are related to their respective areas of expertise; and 5) to foster research opportunities for students and faculty which will bring about new solutions for common problems of the elderly or better ways of coping with them.

Geriatric Medicine Academic Award - NIA: New York Medical College _____

Steven R. Gambert

New York Medical College, Valhalla, NY 10595

Sponsor: *National Institutes of Health*

Purpose—Changes in demography mandate that health professionals be skilled in all aspects of geriatric health care. Institutions of medical education must assume a leadership role in planning and providing for future needs.

Progress—The New York Medical College is deeply committed to the teaching, research, and clinical aspects of geriatrics and gerontology. Located in Westchester County, an area where the number of elderly far exceeds the national average, New York Medical College has a total enrollment of 760 M.D. candidates and over 300 graduate students. In addition, its affiliated clinical programs provide training in a variety of settings, including New York City.

Preliminary Plans—The New York Medical College proposes to establish a program in Geri-

atric Education with a Program Director and a select Geriatric Education Group, both administratively functioning out of a newly created Center on Aging and Human Development. The program will serve to improve the quality and quantity of existing curricula in geriatrics and to help foster additional research and careers in geriatrics and gerontology.

Future Plans—The institution proposes that Steven R. Gambert, M.D., Professor of Medicine and Director of the Center on Aging and Human Development, serve as Program Director and be designated as Awardee for the Geriatric Medicine Academic Award for a duration of 5 years. The Institution's and the Awardee's plans are outlined as well as those for continued support.

NIA Academic Award: University of North Carolina/Chapel Hill

Mark E. Williams

University of North Carolina at Chapel Hill, Chapel Hill, NC 27514

Sponsor: *National Institutes of Health*

Purpose—Primary research interests are focused in geriatric functional assessment. The major research objectives are to help define

risk factors for dependency in the elderly, and to develop effective screening tools to identify persons at risk for functional changes.

Sociocultural Mechanisms of Rehabilitation in Old Age

Gaylene Becker

University of California, Aging Health Policy Center, San Francisco, CA 94143

Sponsor: *National Institutes of Health*

Purpose—Our objectives are: 1) to investigate the problematic issues suggested by the stroke rehabilitation literature, e.g., the influence of age on decisions about rehabilitation, practitioner/patient communication difficulties, lack of continuity in rehabilitation measures, minimal support to families, and health professionals' insufficient awareness of the influence of lifestyles on methods of coping with illness; 2) to address the major limitation of that literature, e.g., the lack of appropriate attention paid to process in stroke rehabilitation.

We will continue collecting data to test our specific research hypothesis, that patterns of intervention in the rehabilitation of stroke patients will be determined by three factors: 1) age of the patient; 2) physician attitudes toward rehabilitation that affect decision making; and 3) family members' perceived role in the patient's rehabilitation and the nature and extent of their supportive efforts.

We plan to follow the rehabilitation process for 125 Mount Zion Hospital stroke patients and their significant family members for 1 year.

Progress—To date, 48 patients are in the study. We plan to select the remaining 77 patients, conduct initial interviews, 3-month followup and 12-month followup interviews.

Qualitative analysis of first and 3-month followup interviews will continue: description of the range, content, and relationships among sociocultural factors that influence the rehabilitation process. Quantitative analysis of first and 3-month followup interviews will begin: common descriptive statistics will be employed to explore a) means and medians for measures of central tendency; b) standard deviations for measures of dispersion; and c) relationships found among variables.

Does Improvement in Mortality Mean Better Health?

Eileen M. Crimmins

University of Southern California, Los Angeles, CA 90089

Sponsor: *National Institutes of Health*

Purpose—The purpose of this research is to answer the following question: Has the recent reduction in mortality among the older population been accompanied by an improvement in health, or has the mortality decline resulted in an increase in the proportion of the older popu-

lation with poor health and/or other physically disabling conditions?

To answer this question, changes and trends in measures of health available from the National Health Interview Survey from 1969 to 1982 will be examined for age-sex-race groups

of the older population. Change in these measures will be compared to change in mortality rates for similar age-sex-race groups over the same time period. The hypothesis to be tested is that declining mortality will be accompanied by increasing morbidity.

In the next phase of the research, mortality and morbidity measures will be disaggregated by cause. Trends in mortality and morbidity from the 10 major causes of old-age mortality will be compared. While it is likely that the relationship between mortality and morbidity

change will vary by cause, we expect to find that, for the major causes of death in old age, decreased mortality will be accompanied by increased morbidity; for most causes morbidity will have been experienced for a longer time at a given level of activity limitation; but the morbidity will not be as severe after the mortality decline as before. For cancer, the only increasing cause of death among the ten major causes in old age, we expect to find both increasing morbidity and mortality.

Morbidity Risk Assessment in the Elderly

Ben T. Williams

University Park Pathology Association, Urbana, IL 61801

Sponsor: National Institutes of Health

Purpose—We plan to design, implement, and test a health risk assessment computer program to generate estimates of the probability of hospitalization, disability, and other undesirable health consequences as a function of medical history, laboratory findings, and health habits. The program, used in conjunction with health examination programs for persons aged 60 and above, will facilitate appropriate screening diagnostic tests and risk reduction interventions. Estimates of health consequences from risk reduction will be used to motivate and reinforce behavior changes.

Phase I is a feasibility study to evaluate existing research regarding the association between health habits and consequences among

the elderly and research on the effectiveness of risk reduction activities in this population. Phase I also includes preliminary analysis of public use datatapes from the National Center for Health Statistics.

Phase II includes further statistical analysis, risk factor quantification, development of program specifications, software production, and instrument testing in a clinical setting.

Phase III is devoted to marketing the program to medical sites where health risk appraisal is commonly used as a health education intervention; the 1984 American Hospital Association questionnaire reported that 17 percent of respondents use health risk appraisal in community outreach programs.

The Lives and Needs of Aging Mentally Retarded Persons

Robert B. Edgerton

University of California, Los Angeles, CA 90024

Sponsor: National Institutes of Health

Progress—All goals set for Year 1 have been met on schedule. Research personnel have been recruited and trained; data indexing and retrieval systems have been completed; a large core sample pool ($N=289$) of psychometrically retarded adults has been generated; based on personal history and demographic data collec-

tion with this core sample, four subsamples have been selected for intensive data collection (60 black and 60 matched white adults—principally for research on communicative competence, 33 young adults currently enrolled in independent living training programs, and four subsamples).

Future Plans—While longitudinal data collection will continue as planned, all four projects anticipate data collection, analysis, and publication in Year 2. Some major topics for Year 2 data analysis are: a network analysis of the personal support systems of independently living adults; a sociolinguistic comparison of competence in giving directions between men-

tally retarded and normal adults; a study of parental beliefs and attitudes about the socioemotional histories of their mildly retarded adult children; a comparison of mathematical skills evoked by a test instrument versus similar skills exhibited by the same persons in everyday life.

Effects of Aging Upon Communication: Prevalence of Hearing Loss

John C. Cooper

University of Texas Health Science Center, San Antonio, TX 78284

Sponsor: National Institutes of Health

Purpose—This group of six projects will investigate otologic, epidemiologic, audiologic, neurophysiologic, morphologic, histochemical, and laryngologic aspects of age-related communication disorders, chiefly clinical presbycusis (hearing dysfunction in the elderly), and presbylaryngis (laryngeal dysfunction in old age). From this information we hope to better understand the pathophysiology of these disorders, develop a new diagnostic test, and establish better-defined hypotheses for future studies, thus adding to our ability to prevent, modify, and eventually treat age-related communication dysfunction.

The first two projects examine the epidemiology of clinical presbycusis and its possible relationship to cardiovascular disease by analyzing the extensive HANES I database (project one) and by studying the auditory function of

the Framingham cohort (project two). Project three will examine the validity and reliability of cochlear distortion-products as an objective test of cochlear dysfunction, using noise-damaged cats and presbycusis baboons and humans. Project four will study the electrophysiologic and morphologic changes in elderly baboons with auditory dysfunction compared to young and aged controls. Project five will study the nerve conduction time, stimulus parameters, and strength of the glottic closure reflex as well as muscle tension properties and morphology in young and aged baboons, in order to isolate the pathophysiologic changes responsible for aspiration in the elderly. Project six will examine changes in steroid receptors in brain and larynx as a function of age and sex in the baboon.

Perceptual Retention and Age

D. Arenberg

NIA, National Institutes of Health, Bethesda, MD 20892

Sponsor: National Institutes of Health

Purpose—One of the goals of this project is to describe adult age differences and changes in nonverbal memory performance.

Progress—Estimates of score changes due to aging based on regression analyses of 24 years of first-time scores on the Benton Visual Retention Test for men were calculated for 10 birth cohorts. The largest estimates of age change

were found for the two earliest born cohorts (1877-1884 and 1885-1892), moderate estimates of change for the next four cohorts (born between 1893 and 1924), and virtually no change for the four latest born cohorts. These results are consistent with individual measures of change obtained longitudinally; substantial change in nonverbal memory occurs only late in life.

Similar regression analyses were used to compare estimates of age change in eight pairs of birth cohorts over the same period of life.

The pairs of estimates of age change in nonverbal memory were quite similar in magnitude and were highly correlated.

Learned Modification of Visceral Function in Man

B. T. Engel

NIA, National Institutes of Health, Bethesda, MD 20892

Sponsor: *National Institutes of Health*

Purpose—This project is concerned with the application of behavioral methods and principles to clinical medicine. Subjects are patients selected from various medical clinics, or normal

subjects, who are studied to evaluate potential clinical methods. The main focus of this project is on clinical problems especially relevant to middle-aged or elderly persons.

Audiologic Findings in Aging Down's Syndrome Patients

A. Pikus

National Institutes of Health, Bethesda, MD 20892

Sponsor: *National Institutes of Health*

Purpose—It is known that over 90 percent of Down's syndrome individuals develop Alzheimer-type dementias as they age. This aging Down's syndrome population is being studied audiologically in comparison with healthy normally aging males and females and in comparison with Alzheimer's patients. Each Down's syndrome patient receives complete audiologic assessments, including baseline and serial measurements of auditory function and electrophysiological studies. Audiologic monitoring of this population is critical for professional and home management, as well as for maintaining

social and vocational development.

Progress—As of May 1, 1985, 25 adult Down's Syndrome patients (18 females, 17 males) have been evaluated audiologically. As this study is ongoing, some preliminary audiologic data was presented at a large meeting of speech and hearing professionals in November 1984. Further analysis of the mixed hearing losses (over 80 percent of this population has some peripheral auditory deficit) will follow completion of data collection.

Modeling Length of Stay for the Hospitalized Elderly

Linda Nichols, Ph.D.; Frederick C. Blow, Ph.D.; William B. Applegate, M.D.; Matthew Ochs, M.D.;

Debra Strasburg, R.P.T., M.S.

Veterans Administration Medical Center, Memphis, TN 38104

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—It has been well documented that hospitalized elderly have longer lengths of stay than younger patients, even though illnesses of aged individuals are not necessarily more severe. Numerous factors relating to age may play a role in increasing the length of hospital stay for the elderly, for example, premorbid

functional impairment, decreased organ reserves, and slower healing time. However, age factors alone do not account for increased length of stay since length of stay is not uniformly increased. Despite the use of age as a common factor in predicting length of stay (e.g., DRGs), not all elderly have lengths of stay

longer than those of younger patients. In addition, some elderly have longer lengths of stay than others, thus contributing disproportionately to the average for all elderly.

Length of hospital stay has traditionally been considered primarily a function of medical and/or clinical factors. However, biological, social, and clinical research on aging has shown that most elderly hospitalized patients present with problems in multiple domains (medical, social, economic, emotional, functional) which interact in complicated ways to influence health care outcomes. It is this interaction that may be instrumental in increasing the duration of hospitalization for many elderly patients.

The major objective of this study is to develop a means of targeting hospitalized elderly at risk for increased length of stay. This study will attempt to develop a model that is both predictive and amenable to intervention to decrease length of stay. The questions include: 1) What factors or domains, single or in combination, contribute to variation in length of stay for hospitalized older adults? 2) Can subpopulations be identified which account for a large portion of the variance in length of stay in hospitalized elderly? 3) Can a risk index be developed which could predict which patients are at risk for increased length of stay?

The 2-year study will be conducted at the VA Medical Center in Memphis, Tennessee. A

sample of 400 patients over age 60 will be drawn from medical service admissions in 4 diagnostic categories: COPD, MI, CHF, and pneumonia. A sample of 100 patients in each of the four diagnostic categories will be interviewed to obtain demographic, social, psychological, and functional information. Clinical course and medical/physical variables will be obtained through retrospective chart analysis. In addition, severity of illness will be rated at admission and over the course of the hospital stay. From these data, it is hoped that risk factors for increased length of stay will be identified.

Preliminary Results—To date, 130 males ranging in age from 60 to 92 years (mean = 68.5 years) have been identified and enrolled in the study. These patients are predominantly white (68.8 percent) and married (62.6 percent) and have experienced multiple hospital admissions in the past 5 years. Of these patients, 118 have been followed through their hospital course to discharge. The mean length of stay for these patients is 9 days with a standard deviation of 8.6 days. The average length of stay for each diagnostic group varies: COPD (7 days); pneumonia (12 days); CHF (5 days); and MI (18 days).

Future Plans—The project will be completed in September of 1987.

A Geriatric Record and Multidisciplinary Planning System

Kenric W. Hammond, M.D.

Jerry L. Pettis Memorial Veterans Administration Hospital, Loma Linda, CA 92357

Sponsor: Health Services Research & Development

Purpose—The GRAMPS project was funded to develop and evaluate a computer-assisted information system for ambulatory geriatric care, which is compatible with the VA Decentralized Hospital Computer Plan. Our aim is to provide a practical system for the primary care physician's office, capable of integrating information over time and across disciplines in a fluid, usable way.

Physician acceptance and usage is essential to the successful introduction of information

systems to primary care. Since the physician is the integrator and formulator of the treatment plan and is responsible for implementing the most expensive interventions affecting patient care and outcome, it follows that information systems must be used daily if they are to fulfill their potential to rationalize and enhance health care and assure that it is cost-effective. Therefore, the information system must perform acceptably in the hands of the average VA physician with minimal training and prepa-

ration. It must effectively communicate patient care information to others and yet allow the non-typist physician to produce a report within the constraints of a clinic encounter. A major challenge of medical information systems development is facilitating rapid capture of medical information in a way that minimally intrudes on the care process, is adequately comprehensive, and flexible enough to deal with a variety of clinical situations.

Ambulatory geriatrics was chosen for development because of its high relevance to the VA's emerging mission, because geriatric clinical strategy is relatively well-defined, and because the benefits from a multidisciplinary geriatric record appear achievable.

Progress—After 14 months of development, the GRAMPS system is approaching these performance standards and progress has been encouraging. A system design, which allows structured manipulation of clinical narrative text promises great flexibility in many areas of medical record keeping. The records generated by

GRAMPS are legible, available on-line and in the chart, and are rapidly updatable. Presently, GRAMPS supports a Physical Exam, a Review of Systems, a Problem List, and problem-oriented Clinic Encounter Notes. Prescriptions, consultation requests and laboratory request slips are generated as by-products of the Clinic Encounter entry.

Future Plans—The system is being evaluated in a 12 month follow-up of 300 Ambulatory Care Clinic patients aged 65 years and older. The care of 150 controls will be managed conventionally, while 150 experimental subjects will be managed with GRAMPS. The study is being conducted in three phases: (1) software development and selection of control subjects, (2) software implementation and enrollment of the study group, and (3) data analysis, system evaluation, software documentation and preparation for export to other VA sites. The study is now in phase 2 and GRAMPS is being used to manage over 100 geriatric cases in the clinic. Phase 3 begins in August, 1987.

Iatrogenic Disease in Hospitalized Elderly Veterans

Dennis W. Jahnigen, M.D.; F. Marc LaForce, M.D.; Carol Hannon, R.N.; Darcy Cooper, R.N., G.N.P.
Veterans Administration Medical Center, Denver, CO 80220

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This prospective longitudinal study was designed to improve understanding the magnitude and variety of adverse events occurring among hospital patients. Predefined criteria for 47 possible complications were developed by a consensus panel. Not all complications were necessarily iatrogenic, but all were judged to be separate from the primary reason that the patient was admitted. All patients over 70 years of age and a random sample of those under 70 who were admitted to the Denver VA Hospital during a 14-month period were enrolled. On admission, a nurse epidemiologist recorded demographic and medical information. Patients were monitored regularly for any evidence of a possible adverse event, change in mental status, or skin condition, or performance of any surgery or other invasive medical

procedure.

These data were reviewed independently by two physicians using the predefined criteria. Complications were classified as major if an intervention was required and minor if not. Agreement was over 90 percent and intraphysician variability was < 5 percent in designating complications.

Results—Twelve hundred and thirty-four patients were enrolled between July 1984 and August 1985. Sixteen hundred and twenty-one adverse events occurred among 479 patients. Of these, 642 complications in 253 patients were major. The percent of patients experiencing a specific type of adverse event was as follows: infection, 13.2 percent; surgical, 9.0 percent; adverse drug reaction, 5.3 percent; psychiatric de-

compensation, 5.7 percent; invasive procedure, 2.5 percent; trauma, 2.0 percent. Patients with greater severity of disease were most likely to have a complication ($r = 0.84$); increasing age was also a strong predictor ($r = 0.74$). In 186 patients, the adverse event was felt to have increased the length of stay.

Other analyses suggest that, for certain categories of adverse events, rates are high at the beginning of the academic year (July) and progressively decline. This suggests that educational interventions may be useful in reducing certain types of adverse events. Subset analysis

of specific types of complications is under way in an effort to detect clinically useful predictors. For example, mild abnormalities on a screening mental-status examination appears to be predictive of falls while in the hospital.

Future Plans—A final expected outcome from the project is development of a useful methodology for continuous surveillance for adverse events. Refinement of our techniques may well lead to a clinically useful program which other institutions can adopt.

Computer-Based Expert System for Geriatric Psychiatry

Gerhard Werner, M.D.

Highland Drive Veterans Administration Medical Center, Pittsburgh, PA 15206

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to demonstrate the feasibility of a diagnostic system in geriatric psychiatry, with a goal of illuminating steps in the process of apprehending the patient's clinical findings as diagnostically meaningful configurations.

Progress—The program consists of two parts, both implemented in the PROPHET network's modified PL-1 language. The first comprises the acquisition and entry of data in the patient's intake interview. This component of the program consists of 62 independent procedures whose sequence of activation is determined by the circumstances of the patient's referral and the availability of additional information (e.g., from accompanying family members, previously obtained laboratory findings, and the history of past illnesses and treatments).

The second part is the diagnostic program which comprises the four stages described below.

1) Pattern matching. The knowledge base contains lists of symptoms for each of 19 syndromes currently considered by this system, ordered in three arrays as "must have", "may be associated with", and "must not have".

The pattern match concludes with ranking the candidate diagnoses by "degrees of fit"; the

criterion for ranking the representativeness of a syndrome is the number of matching symptoms in the "must have" category reported by the largest number of independent sources. Complaints which remain unmatched are stored for future reference.

2) Integration of knowledge sources, and interactive acquisition of additional patient information. Procedures that interrogate the patient database for information that may be relevant for each of the candidate syndromes generate a trace of their findings. Each of these procedures is an independent condition-action module which communicates messages and can, in turn, activate other knowledge sources. Essentially, the principle of HEARSAY II is followed, with the ranked candidate syndromes serving as the schedulers for the invocation of knowledge sources.

3) Parsing the trace. The completion of the trace for each of the candidate syndromes is followed by the evaluation of the trace in its entirety. As shown in the sample output, the generation of the trace is linked with candidate hypotheses; but information contained in it may also be relevant for other syndromes, or even for the syndromes which were temporarily excluded on the basis of pattern matching and did not, therefore, make the candidate list. The

trace is parsed to classify each entry in the trace as either being a possible antecedent, or a possible consequent manifestation of each of the 19 geriatric syndromes tracked.

4) Summation of the diagnostic process. The purpose is to summarize the state of the diagnostic process at the end of the patient's intake interview. The resulting message to the examiner includes the supporting evidence for the choice of one or each of several equally plausible diagnoses, and specifies unresolved aspects of the diagnostic problem.

Preliminary Results—In 38 of 45 geriatric pa-

tients who underwent intake assessment by this program, at least one of the program-generated diagnoses was identical with the independent clinical judgment. Syndromes were correctly identified in 41 instances. In 17 cases, the program produced alerting evidence for complicating circumstances (e.g., medication use, nutritional deficits associated with prior surgical interventions, past history of head trauma, and the like) which had not been attended to in the independent clinical judgment. Incomplete anamnesis in the intake interview provided the control clinician an incomplete database in six instances.

Falls in the Elderly: A Randomized Study of Intervention and Impacts

Laurence Z. Rubenstein, M.D., M.P.H.; Alan S. Robbins, M.D.; Barbara Schulman, R.N., M.S.N.; Karen Josephson, M.P.H.

Sepulveda Veterans Administration Medical Center, Sepulveda, CA 91343

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Falls and gait disorders among the elderly are extremely common and account for substantial morbidity and mortality. Fall rates for institutionalized elderly have been estimated to range from 400 to 1,500 falls per 1,000 patients per year, and from 10 percent to 15 percent of this group will suffer from serious fall-related complications each year. Falls are also a serious problem for noninstitutionalized elderly. About one-third of the elderly living at home will fall each year and about 1 in 40 of these will be hospitalized. Of those hospitalized after a fall, the mortality rate is extremely high—only about half will be alive a year later.

Previous studies have described the epidemiology of falls and attempted to identify associated risk factors. While recommendations exist for reducing rates of falls, none has been subjected to a rigorous clinical trial. As a result of this uncertainty, patients frequently do not receive careful diagnostic assessment after a fall. In addition, there are major knowledge gaps in both the basic epidemiology and pathophysiology of falls, the utility of specific diagnostic tests, and prognosis. It is clear that any definite study of falls in the elderly must address the multifactorial and interrelated causes

involving the cardiovascular, neurologic, and musculoskeletal systems, as well as environmental factors and the use of drugs.

The purpose of this 3-year study is twofold: 1) to define the epidemiology, etiologies, appropriate diagnostic assessments, and therapeutic interventions for institutionalized and community-living elderly; and 2) to apply sophisticated technology in order to critically evaluate instability and gait disorders (hypothesized as the most relevant predictors of falls). The experimental design has three components: 1) a randomized controlled study of institutionalized and community-living elderly who fall, that assesses the value of a multidimensional diagnostic evaluation and therapeutic intervention; 2) application of specialized diagnostic procedures (e.g., stride analyzer and autonomic nervous system testing) to better define the pathophysiology of falls and determine the utility of special diagnostic testing; and 3) a case-controlled study of institutionalized fallers and nonfallers (utilizing diagnostic approaches previously found to be valuable) to assess the value and risk of therapeutic interventions (e.g., gait training; use of centrally-acting drugs).

Progress—Study patients are recruited from an outpatient general medicine clinic, a 325-bed skilled nursing facility, and a 375-bed board-and-care facility. To be eligible for the study, patients must be 65 years of age or older, ambulatory and not severely demented or medically unstable. Clinic patients are identified through self-reporting of falls at the time of a clinic visit. Institutionalized patients who have fallen are identified by incident reports. Patients who agree to participate in the study are asked to describe their fall, and baseline medical and functional data are collected. Patients are then randomly assigned to either the experimental (intervention) or control (nonintervention) group.

The experimental group is given the assessment protocol by a research nurse practitioner (NP).

The diagnostic protocol performed by the NP consists of: 1) a complete medical history; 2) a detailed "fall history"; 3) a standardized functional status questionnaire validated for institutionalized elderly—Lawton modification of the Katz ADL and IADL scales; 4) a physical examination (including a detailed neurologic and musculoskeletal assessment, mental status and depression testing, postural blood pressure determination, balance and gait assessment); 5) routine blood and urine tests; 6) a standard 12-lead electrocardiogram; 7) a 24-hour ambulatory cardiac (Holter) monitoring; 8) stride analysis using the foot-switch system developed by the Rehabilitation Department at the Rancho Los Amigos Hospital; and 9) an assessment to document environmental hazards. Diagnostic impression and therapeutic recommendations for experimental patients are given to the primary physicians. Patients in the nonintervention control group are followed by the NP using chart abstract and receive only the diagnostic and therapeutic procedures ordered by the patients' own physician.

Followup data are being collected on each patient (both in the intervention and nonintervention groups) for 2 years at 3-month intervals following randomization. Data collected in-

cludes outcome measures of specific therapy, subsequent falls, survival, functional status, and use of medical services.

Preliminary Results—Randomization of community-living elderly into the study began in July 1986. To date, 75 subjects have been enrolled—35 cases and 40 controls. Among community-living elderly screened for the study ($N=714$), 29 percent reported having fallen in the previous 12 months. Of those who had fallen, 37 percent were randomized into the study. (32 percent refused randomization and 31 percent were ineligible because of medical instability or distant living location.) Preliminary analysis of initial descriptive variables collected prior to randomization revealed no statistically significant differences between cases and controls, consistent with random assignment. The mean age for this group is 71 years and 93 percent are male. The most frequent etiologies of falls among these patients were orthopedic problems (32 percent), neurological problems (24 percent), environmental hazards (21 percent), postural hypotension (6 percent), and syncope (5 percent).

Randomization of institutionalized subjects began in October 1986. During the first 6 months of the randomization phase, 487 falls involving 247 patients were reported. Forty-one percent of those who fell were subsequently randomized into the study—51 cases and 50 controls. Twenty-four percent of the patients who fell were not randomized because the fall was reported after our 7-day cutoff point. Another 12 percent were too demented or medically unstable, while 9 percent were unable to ambulate and 14 percent refused randomization. Study patients are predominantly female (80 percent) and have a mean age of 86 years.

Enrollment of patients into the study will continue for another 6 to 9 months. Mortality and dropout rates among study patients have been exceptionally low, and we anticipate completing detailed 2-year followup on the majority of patients.

XVI. Miscellaneous

Age-Related Changes in Sensorimotor Performance

Barbara M. Myklebust, Ph.D.; Sander Glatt, M.D.; Joel B. Myklebust, Ph.D.; Larry Nosse, M.S.; Mary Ann Dettmann, M.S.; Marcie Lindner, M.S.; Bernie Cohen, Ph.D.; Rick Saltzstein, M.D.

Veterans Administration Medical Center, Milwaukee, WI 53295

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this study is to identify sensorimotor parameters of aging in normal subjects and in patients with injuries to the central nervous system. It will compare responses of normal adults and CNS-injured patients with respect to evoked potentials, vibratory sensation, walking and standing patterns, muscle responses in gait, quiet standing, and activities of daily living. Muscle responses following tendon taps, muscle stretch, electrical stimulation, and simple voluntary limb move-

ments will also be monitored.

Normal adults (ages 18-90 years) and patients with stroke, spinal cord injury, traumatic head injury, amyotrophic lateral sclerosis, Parkinson's disease, Alzheimer's disease (dementia), multiple sclerosis, cervical spondylotic myelopathy, cerebral palsy, and patients who are classified as frequent fallers will be tested. The normal data will be evaluated for changes with aging and will be used as a baseline for the evaluation of the pathologic conditions.

Chest Wall Stiffness in Patients with Chronic Respiratory Muscle Weakness

Marc Estenne; Andre Heilporn; Louis Delhez; Jean-Claude Yernault; Andre de Troyer

Chest Service, Erasme University Hospital, Brussels School of Medicine, 1070 Brussels, Belgium

Sponsor: None Listed

Purpose—Using the weighted spirometer technique, we studied chest wall compliance (C_w) in 16 nonobese patients with chronic weakness of the respiratory muscles and 20 healthy control subjects. In order to evaluate the validity of the technique, while C_w was being measured, we monitored thoracoabdominal configuration with two pairs of linearized magnetometers and electrical activity of the external oblique with a concentric needle electrode in three healthy subjects and four patients; in addition, we recorded in three subjects the electrical activity from the intercostal muscles and diaphragm throughout the procedure.

The method was reproducible within 5.8 percent and provided C_w values that compared well with those yielded by the relaxation technique. In each subject, the weight-induced shifts in end-expiratory lung volume showed a very good linear correlation with the changes

in transrespiratory pressure and end-expiration ($r=0.91$). In addition, in none of the subjects tested did the electromyograms reveal any intercostal, diaphragmatic, or abdominal muscle activity at end-expiration, nor did the end-expiratory level ever show a significant departure from the relaxed thoracoabdominal configuration, thus suggesting adequate respiratory muscle relaxation. The reduction in inspiratory muscle force in the patients ranged from 17 to 94 percent of predicted (mean \pm SE, 43 ± 6).

The decrease in vital capacity, total lung capacity, and functional residual capacity averaged 59, 34, and 15 percent of predicted, respectively. Both the patient and the control groups showed a large interindividual variability regarding C_w . It varied from 0.117 to 0.258 L/cm H_2O (mean \pm SE, 0.162 ± 0.012) in the patients and from 0.163 to 0.366 L/cm H_2O (mean \pm SE, 0.248 ± 0.013) in the healthy subjects. The C_w

value was below the control range in 12 of the 16 patients and the difference between the patient and control groups was significant ($p=0.001$). We conclude that: 1) the weighted spirometer technique allows accurate measure-

ments of chest wall compliance to be obtained; and 2) chest wall stiffness develops in patients with longstanding weakness of the respiratory muscles.

Noninvasive Quantitation of Venous Reflux

Bok Y. Lee, M.D. and Lee E. Ostrander, Ph.D.

Veterans Administration Medical Center, Castle Point, NY 12511 and Rensselaer Polytechnic Institute, Troy, NY 12181

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Chronic venous insufficiency can impair patient mobility but is difficult to assess due to the lack of objective, noninvasive, and routinely usable clinical tests. To improve assessment, we have developed a test for quantitative measurement of venous reflux and for separate identification of deep and superficial involvement. The test is noninvasive and requires minimal patient cooperation. The total venous reflux measurement system uses an inflatable boot placed over the lower limbs from foot to below the knee, in the seated subject. The boot is inflated to 60 mm Hg, and calf volume is measured by impedance plethysmography when the boot pressure is abruptly released, allowing blood to return to the limb. Changes in impedance with time measure the

rate of change in volume and therefore blood flow. To obtain a separate measurement of deep venous reflux, a tourniquet is placed above the knee to impede flow through the superficial system, and the test is repeated. To calculate superficial reflux, one subtracts deep reflux from total reflux.

Results—Evaluation of the method was carried out in a series of 89 limbs. A grouping of 35 limbs according to venography findings showed that the test of total reflux provided a differentiation of patients according to the presence of primary and/or secondary varicosities. The superficial reflux measurements provided a further differentiation of patients with primary varicosities.

The Definition of "Peer": Consumer Perspectives and Significance in the Delivery of Counseling Services

Margaret A. Nosek, Ph.D.

Baylor College of Medicine and ILRU Research and Training Center on Independent Living at TIRR, Houston, TX 77225

Sponsor: National Institute of Handicapped Research

Purpose—This project is intended to provide initial data on the perceptions of disabled persons with respect to the definition of peer and the provision of counseling services by peers. Consumers' opinions will be solicited on characteristics of peer counselors which enhance credibility and lead to highest levels of satisfaction with peer counseling services delivered by independent living centers.

Progress—In this initial investigative effort, the research has been delimited to three dis-

ability groups—mobility impaired persons, visually impaired persons, and hearing impaired persons. After the methodology has been developed and validated, additional research might focus on other disability groups. The methodology will involve the development and pilot testing of the content and format for an interview survey; training of interviewers who will collect the data; collection of data from disabled individuals using the interview approach in various geographical locales to obtain a sample that is diverse with respect to age, ethnic mix, type of

disability, and socioeconomic status; analysis of data collected from disabled consumers; and articulation and dissemination of research findings.

An extensive literature review has been conducted. Using information from this search and input from senior project consultants, the interview content and format for the consumer survey are being developed.

A new dimension has been added to this

study in response to the completion of the national evaluation of independent living centers conducted by Berkeley Planning Associates. This evaluation gathered much information of relevance to the Center's study. The consultant services of Berkeley Planning Associates are being obtained. This valuable resource is currently being explored for conclusions and insights regarding the relationship of concepts of "peer" to independent living outcomes.

Predicting the Success of Lumbar Sympathectomy in Patients with Severely Ischemic Foot

Bok Y. Lee, M.D.

Veterans Administration Medical Center, Castle Point, NY 12511

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The role of lumbar sympathectomy in the management of patients with arteriosclerotic occlusive disease of the lower limbs remains a subject of considerable discussion. Much of the confusion concerning lumbar sympathectomy is due to a lack of procedures that accurately and sensitively select those patients to whom lumbar sympathectomy may be of benefit. We have carried out a retrospective review of 101 lumbar sympathectomies to examine the role of a distal thigh (above-knee)/arm systolic pressure index in selecting patients for lumbar sympathectomy. Previously, we have established criteria using doppler systolic ankle pressure, ankle to brachial systolic pressure ratio, external magnetic flowmetry measurements of peak pulsatile calf blood flow, and thermistor thermometry in selecting patients for lumbar sympathectomy.

Progress—Our experience has shown that lumbar sympathectomy as an initial operative procedure is of benefit to patients with severe ischemia of the foot and gangrene secondary to atherosclerotic occlusive disease. We have further reviewed our experience with lumbar sympathectomy in patients with toe gangrene not amenable to direct arterial surgery.

Results—Of the 101 lumbar sympathectomies, 11 were excluded due to concomitant direct ar-

terial surgery or from being lost to followup. Data presented are thus based on 90 lumbar sympathectomies done on 82 male patients. The beneficial effects of lumbar sympathectomy were the relief of symptoms, the prevention of major amputation, or an improvement in disabling intermittent claudication. In these patients, it was found that a doppler systolic above-knee/brachial pressure index of 0.60 or better and an external magnetic flowmetry mean calf bloodflow of 30 ml/min or greater were found to be good predictors of a beneficial effect from lumbar sympathectomy. These data are currently being prepared for publication.

The benefit of lumbar sympathectomy in the management of gangrene in patients not amenable to direct arterial surgery was examined in 45 patients (50 limbs) with gangrene limited to the toes, 31 patients (32 limbs) with gangrene of the foot, and 8 patients (11 limbs) with gangrenous involvement of the leg. At 8 years, the cumulative toe salvage rate of patients with toe gangrene was 51 percent and cumulative limb salvage rate was 71 percent. The cumulative survival rate in three patients at 1 to 2 years was 71 percent and at 5 to 6 years was 40 percent. The presence of diabetes did not significantly influence limb or toe salvage. In most patients with digital gangrene not amenable to direct arterial surgery, lumbar sympathectomy works to salvage limbs and toes.

A Short Awareness Course on Microcomputers in Rehabilitation and Special Education

B.R. Seeger, Ph.D.; R.E. Garrett, B. Tech. Grad. Dip. Maths.
Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: *None Listed*

Purpose—The introduction of microcomputers into rehabilitation has had a significant impact on the range of devices and software available for disabled people. It is often difficult for health professionals and special educators to gain the firsthand experience necessary to appreciate the potential of this new technology.

Progress—To overcome this problem, we have been conducting a 1-week awareness course titled "Microcomputers in Rehabilitation and

Special Education" for people who want to apply microcomputers in rehabilitation or education of children and adults with physical disabilities. The course includes lectures, demonstrations, and hands-on experience using 17 Apple IIe computers. A comprehensive set of notes and tutorials has been generated and participants are supplied with a copy of public domain software, manuals, and a switch. This course is funded from registration fees.

Cardiac Rehabilitation: Preliminary Results and Treatment Efficacy

Susan S. Daly, Ph.D.; Edward J. Hickling, Psy.D.; Maria-Paz Alfonso, M.D.; Kurt C. Euller, Ph.D.
Veterans Administration Medical Center, Albany, NY 12208

Sponsor: *VA Medical Center, Albany, NY*

Purpose—We use a multidisciplinary team approach to provide a comprehensive pragmatic 10-week cardiac rehabilitation program for veterans. This program emphasizes physical activity to promote physical and cardiovascular fitness. Education and counseling seek to identify and correct or modify risk factors, increase knowledge of the pertinent aspects of the patient's heart disease, and to evaluate and improve psychosocial factors influencing the development of, and recovery from, heart disease. Group sessions are held three times per week for both exercise and risk factor modification. Individual intervention around any targeted risk factor or concern is provided as needed.

Progress—Two studies were designed in an effort to evaluate the effectiveness of this comprehensive approach to cardiac rehabilitation. In Study 1, the charts of 44 randomly selected male cardiac rehabilitation patients were reviewed retrospectively to evaluate the success of the cardiovascular fitness aspect of the program. The mean age of the patients was 59,

with an age range from 48 to 79 years. Twenty-one of the patients had undergone coronary artery bypass grafts (CABG). Risk factors assessed included hypertension, family history of heart disease, smoking, diabetes, and hyperlipidemia. Of the 44 patients, 13 had one risk factor in their history or life style, 13 had two factors, 11 had three factors, and four patients had four risk factors. Using the New York State Heart Association Functional Classification (NYSHAFC) system, two patients were rated Class II, 35 patients were rated Class III, and seven patients were rated Class IV. Post-treatment significant cardiovascular improvements were demonstrated by changes in functional classification, energy expenditure, and increased oxygen consumption. Age, number of prior risk factors, and previous CABG surgery were not significantly correlated with cardiovascular improvement.

Study 2 was conducted to examine the effectiveness of group and individual modification of selected targeted behaviors. Subjects were 18 male veterans who completed the 10-week car-

diac rehabilitation program. The mean age was 58.1 years. Fifteen of the subjects were married; two were separated, and one was widowed. Fourteen of the subjects were retired; two returned to work, and two were unsure of their status. Average self-reported onset of CAD was 5.35 years. The mean number of risk factors, using the American Heart Association guidelines, was 5.5. Each subject completed pre-treatment and post-treatment assessment batteries which included the Jenkins Activity Survey (JAS), Beck Depression Inventory (BDI), Multidimensional Health Locus of Control (MHLOC), the Hopkins Symptom Checklist (HSCL), and the Albany Cardiac Rehabilitation Program Questionnaire (ACRPQ). The ACRPQ was developed by the program to gather background data, and to assess risk factors and self-reported ratings of knowledge of heart disease, and satisfaction with physical functioning and emotional well-being.

Post-treatment subjects reported a significantly greater satisfaction with physical and emotional functioning. The HSCL also demonstrated significant improvements on the mean

total scores, and on subscales which measured interpersonal sensitivity, somatization, and agitated depression. There were no significant changes found across treatment for the BDI, STAI, or MHLOC scores. The ACRPQ failed to show significant changes on measures of ability to handle stress, number of physical exercise, sleep, blood pressure, weight, pain or smoking cessation, although trends for improvement were noted in several of these categories. Post-JAS scores were not analyzed because the large number of subjects who were unemployed invalidated the test scores.

Future Plans—Based on the encouraging results on the above studies, which demonstrate the effectiveness of such a program for the older, generally retired, veteran population, a 3-year grant proposal has been submitted to HSR&D. This proposed study would allow for a controlled comparison of this multifaceted treatment program with a more traditional medical treatment approach. In addition, it would use a more comprehensive data and a larger population.

Reliability and Validity of CT and NMR

James Fletcher, M.D.

Veterans Administration Medical Center, St. Louis, MO 63125

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objectives of this research are to assess the inter-observer reliability, intra-observer reliability, and the validity of computerized tomography (CT). Variables such as type of machine, setting, years of observer experience, and anatomic site will be explored for effects on reliability and validity.

Progress—The design incorporates six body readers from three different settings and three neuro readers from three different settings. The sample scans were randomly selected from each of three sites with equal numbers in three anatomic areas and read independently by each reader in a blind fashion. Each of the three neuro readers have currently read all 90 scans in the original data set. Manual scoring of the

interpretations is well under way.

Scoring has been divided along several dimensions. First, each reader was asked to provide a general abnormality score from the following list: 1) definitely abnormal; 2) probably abnormal; 3) questionably abnormal; 4) definitely normal; 5) technically unsatisfactory. Three criteria are being used to judge agreement along this dimension. Second, the interpretations are being scored for agreement on specific location of the abnormality (i.e., the "slice" of the scan which exhibits the abnormality best). Third, the interpretations are being scored for agreement on etiology, diagnosis, and other findings. All interpretation pairs which yield disagreements are reviewed and scored by an independent physician.

Two of the three neuro readers have completed reading one half of the original data set for inter-observer reliability. Scoring of this data set is as described above. Five of the six body readers have completed reading the original 180 body scans in the original data set. The sixth reader has less than 30 scans to finish the set. No body reader has begun the rereading process to assess intra-observer reliability.

All inpatient records have been reviewed at

each of the three participating institutions in order to assess validity of the study interpretations. Information such as discharge diagnosis, evidence for diagnosis, and original clinical interpretation of the scan has been extracted from the clinical records. Outpatient records are still being sought. Validity will be assessed using receiver operating characteristic (ROC) curves which will allow significance testing for area under the curve.

Skin Blood Flow by Helium Flux Effect of Skin Temperature

Gordon R. Neufeld, M.D.; Stephen R. Galante, B.S. Ch.E.; James E. Baumgardner, M.D., Ph.D.; Joyce Whang, B.S. Ch.E.; David J. Graves, Sc.D.; John A. Quinn, Ph.D.

Departments of Anesthesia and Chemical Engineering, University of Pennsylvania and Division of Anesthesia Research, Veterans Administration Medical Center, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Baumgardner (1985) described a new technique for measurement of skin blood flow using helium flux in people. He found, in a limited number of normal subjects, a large change in blood flow with increasing skin temperature over the range of 34 degrees C to 44 degrees C. We confirmed the temperature-dependant effects of skin blood flow in 36 normal human volunteers, and compared our data to those of Baumgardner's original study.

Progress—Normal human subjects breathed a mixture of 80 percent helium and 20 percent oxygen via a tight-fitting face mask and anesthesia breathing circuit. After equilibration with the breathing mixture (15 to 30 minutes), helium flux through the skin was measured by passing 100 percent nitrogen over the skin

through a temperature-controlled skin probe (2.5 cm diameter). The nitrogen sweep stream was analyzed for helium by a helium leak detector (Leybold-Heraeus Model M2) located downstream from the probe. Steady-state flux rates of helium were determined at each temperature of the probe, which was gradually increased from 33 degrees C to 42 degrees C in steps.

Results—The results are comparable with the original data of Baumgardner, corrected by a factor of 2 for the skin probe area actually swept by nitrogen. We conclude that skin blood flow measured by helium flux increases with skin temperature in a linear fashion between 33 degrees C and 42 degrees C.

Comparison of Helium Flux and Laser Doppler Skin Blood Flow Measurements: Effect of Skin Temperature

Gordon R. Neufeld, M.D.; Stephen R. Galante, B.S. Ch.E.; Cheryl A. Reilly, R.N., B.S.N.; James E. Baumgardner, M.D., Ph.D.; David J. Graves, Sc.D.; John A. Quinn, Ph.D.

Departments of Anesthesia and Chemical Engineering, University of Pennsylvania and Division of Anesthesia Research, Veterans Administration Medical Center, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Laser doppler velocimetry is a totally noninvasive rapid technique for evaluation of skin blood flow. Unfortunately, it is not quanti-

tative, and it is difficult to compare readings among different patients or even at different locations on the same patient. We have studied

the change in laser doppler (Periflux PF2) skin blood flow measurement of patients resulting from a step change in temperature, and found that the increase in laser doppler signal correlated well with skin perfusion as assessed by fluorometry. The purpose of this study was to compare laser doppler velocimetry in normal volunteers and helium flux blood flow determinations (Baumgardner, 1985) over a range of temperatures.

Progress—We constructed an accurately controlled metal temperature probe for the laser doppler and applied it to the skin of the volar aspect of the forearm in normal volunteers. Adjacent to the laser probe, we attached the helium flux probe (also temperature controlled) for measurement of transcutaneous helium

flux. All subjects breathed a mixture of 80 percent helium and 20 percent oxygen for 15 to 30 minutes to achieve a constant blood tension of helium. We recorded the helium flux and laser doppler signals continuously while the probe temperatures were increased from 36 degrees C to 42 degrees C in three degree C increments.

Results—We found that both signals increased with temperature and that the laser doppler data agreed with previously published work (Enkema, et al., 1981). We conclude that laser doppler velocimetry increased nonlinearly with blood flow in agreement with others. Change in the optical properties of the skin to laser light or increase in static blood volume with temperature are possible causes of this effect.

Comparison of Helium Flux and Xenon Washout of Skin Blood Flow Measurements in Man

Gordon R. Neufeld, M.D.; Stephen R. Galante, B.S. Ch.E.; James E. Baumgardner, M.D., Ph.D.; Joyce Whang B.S. Ch.E.; David J. Graves, Sc.D.; John A. Quinn, Ph.D.

Departments of Anesthesia and Chemical Engineering, University of Pennsylvania and Division of Anesthesia Research, Veterans Administration Medical Center, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The reference standard for all skin blood flow measurements is generally regarded to be the Xenon washout technique described by Sejrsen (1969). Baumgardner et al. (1985) described a helium flux technique for quantitative skin blood flow measurements. This technique measures the quantity of helium transported through the skin to a small heated probe, while the subject inspires a known helium-oxygen mixture. A mass balance equation is used to compute blood flow under the probe using a model equation which requires an estimate of the diffusional resistance of the stratum corneum to helium.

Results—In six subjects, we compared the

helium flux skin blood flow determinations at 33 degrees C to those of the classic epicutaneous Xenon washout technique. Diffusional resistance of the stratum corneum was assumed equal to zero in each subject by measuring helium flux after vigorous skin stripping with adhesive tape. When the results of the two methods were plotted as blood flow per unit area of skin (Q/A) in ml/min/cm², the blood flow measured by helium flux was approximately double the value determined by Xenon washout technique. The discrepancy between the two methods may be related to the underlying assumptions of the model equations used to calculate the blood flow or to errors in estimation of diffusional resistance.

Evaluation of Cutaneous Blood Flow in Dysvascular Patients and Normals: Laser Doppler and Fluorometry

Gordon R. Neufeld, M.D.; Cheryl A. Reilly, R.N., BSN; Andrew B. Roberts, M.D.; David J. Graves, Sc.D.; John A. Quinn, Ph.D.

Departments of Anesthesia and Chemical Engineering, University of Pennsylvania; Division of Anesthesia Research, Veterans Administration Medical Center; and Division of Vascular Surgery, Medical College of Pennsylvania, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Laser doppler velocimetry is a totally noninvasive rapid technique for evaluating skin blood flow. Unfortunately it is not quantitative, and individual readings are difficult to interpret or compare over different regions of the body or from day to day. We found that the laser doppler response to a skin temperature increase provided a consistent but nonlinear change in signal for an increase in blood flow measured independently. This nonlinear response has been shown by others. These temperature-induced flow changes proved much more useful than the absolute level of indicated blood flow in assessing patients.

Progress—We studied 5 normal healthy volunteers and 20 patients with peripheral vascular disease. The increase in laser doppler signal in

response to a step increase in skin temperature (T) over the range of 32 degrees C to 44 degrees C in two 6-degree increments was fit empirically to an exponential function: $f(T) = A^{bT}$. The rate constant b was found to yield the most consistent results with respect to skin blood flow and clinical outcome.

The 20 patients coming to amputation were retrospectively divided into two groups. Group I included all patients with amputations at the transmetatarsal level or below that healed (N=7). Group II included all patients requiring amputations above the transmetatarsal level (N=13). We concluded that the response to a temperature challenge yields consistent results comparable to fluorometry for evaluation of skin blood flow.

Return to Work After Cardiac Rehabilitation

H.M. Goeminne; K.M. Poelemans; F.E. Rademakers; D.L. Brutsaert
University Hospital U.Z.A., B2520 Antwerp, Belgium

Sponsor: None Listed

Purpose—Over a 3-year period, data were obtained in 281 patients on the time they returned to work (TRW), their professional reclassification (PR), and the type of cardiovascular disease (CVD) they have. These data were correlated with profession (P) and age (A). Cardiac rehabilitation was based on an accelerated program, i.e., with phase two (outpatient phase) immediately following the hospitalization phase (1 to 2 weeks) for a total duration of 3 months (3x1 hr/week), with alternating ECG-controlled dynamic exercises.

Results—The obtained results showed the following. 1) Sixty-two percent of the 281 patients were economically still fully active prior to the

CVD; of this active subgroup 75 percent returned to work after completing the rehabilitation program. 2) TRW versus P — self-employers and professionals return earlier to work than blue collar workers. 3) TRW versus A — the older the patient, the longer the time until returning to work. 4) TRW versus CVD — after coronary bypass, patients return to work sooner than after infarction. 5) PR versus P — a high percentage of self-employed and white collar workers resume work sooner when the working conditions are restructured. 6) PR versus A — elderly persons with problems of professional reintegration often retire prematurely. 7) PR versus CVD — postinfarction as well as post-bypass patients resume work with or without

restructuring of working conditions. Accordingly, factors with a negative influence on work resumption are higher age, blue collar status, and

the impossibility of appropriately restructuring working conditions.

New Technique for Dynamic Exercise Echocardiography

F.E. Rademakers; G.A. Claes; T.C. Gillebert; D.L. Brutsaert
University Hospital U.Z.A., B 2520 Antwerp, Belgium

Sponsor: *None listed*

Purpose—The use of two-dimensional echocardiography to quantify ventricular function in cardiac patients during peak dynamic exercise is hampered by various technical difficulties, mainly related to movements of the thorax and interposition of lung tissue. We developed an exercise system designed to combine: 1) relaxation of all thoracoabdominal muscle strain even at maximal workload; 2) supported abduction of the left arm to optimize rapid and accurate selection of echowindows; 3) left lateral (adjustable range from 90 degrees to 170 degrees) position. In order to relax thoracoabdominal muscle strain, dynamic exercise was per-

formed by alternating oscillatory movements of both legs with fixation of both knees and hips, thereby mobilizing all major muscles of the lower limbs. Resistance to the oscillating movement could be calibrated electronically in both directions up to 150 watts (steps of 15 watts). The cardiovascular response ($N=20$ healthy subjects) at peak exercise was compared at a similar workload on a standard bicycle and treadmill ergometer. It was shown that this innovative technique allows high resolution 2DE measurements in cardiac patients during peak exercise in the absence of any major thoracoabdominal interference.

Data Collecting, Analysis, and Reporting Via Computer in Cardiac Rehabilitation Programs

F.E. Rademakers; P.J. Beckers; D.L. Brutsaert
University Hospital U.Z.A., B 2520 Antwerp, Belgium

Sponsor: *None Listed*

Purpose—Cardiac rehabilitation (CR) has gained its place in the treatment of a variety of cardiac diseases, either as an adjuvant to medical and surgical treatment, or as a first choice treatment in some diseases as well as in primary and secondary prevention. A multidisciplinary team provides comprehensive care for the multiple problems of the cardiac patient. Objective evaluation of such a multidisciplinary treatment is difficult in view of the multiple angles of attack through which a CR program interacts with cardiac disease and its risk factors. In order to correctly evaluate such a CR program, multivariate analysis is needed.

Progress—A specific computer program was designed to fulfill this goal. A suitable input format was chosen to facilitate the work of the team members and to reduce computer time. The program structure can be summarized as follows: patient entry (administrative, medical, social, and psychological data); session entry (medical and exercise data); output (reports on medical status and evolution, psychosocial evolution, exercise parameters and problems, prognosis, and tariffication); storage (short- and long-term statistical analysis). Experience with statistical analysis thus far has been based on a total of 400 patients.

Rehabilitation Aid

M. Evans

Oxford University, Nuffield Orthopaedic Centre, Headington, Oxford OX3 7LD England

Sponsor: *None Listed*

Purpose—"Magpie" is a foot-operated manipulator for use by anyone who has lost upper limb function but who has reasonable lower limb function. The device is a purely mechanical system which translates four independent foot

and leg movements to a mechanism operating at table top level. This unit enables the patient to regain a degree of independence by performing such tasks as self-feeding, typing, shaving, and other personal needs.

Environmental Control

A.I. Tew, B.Sc., and J.D. Harris, C.Eng.

Oxford University, Nuffield Orthopaedic Centre, Headington, Oxford OX3 7LD England

Sponsor: *None Listed*

Purpose—The "Swift" system has been developed to enable the severely disabled to operate remotely a number of electrically powered devices, including a telephone, by means of a small portable transmitter. A wide range of input controls are available to meet the specific

needs of the patient. "Swift" is at the moment undergoing a 6-month comparative trial together with the "BEC 1" environmental control. Both systems are to be used by patients who have had no previous experience of operating this type of equipment.

Evaluation of Rehabilitation Technology

Dennis W. Gilstad, M.D., Ph.D.

Rehabilitation Engineering Center, Southwest Research Institute, San Antonio, TX 78284

Sponsor: *National Institute of Handicapped Research*

Purpose—The SWRI-REC emphasizes research efforts relating to the development of strategies, procedures, and criteria for evaluation of new rehabilitation products and clinical techniques. These efforts also include the study of requirements for acceptance by cognizant regulatory agencies. Evaluation activities conducted or managed by the SWRI-REC staff combine elements of engineering test and analysis for safety, reliability, and maintainability; informal user field trials to check appropriateness and sample potential functional problems; and longer-term, formal clinical evaluation. A team approach to evaluation allows use of the diversity of engineering expertise that resides in the SWRI staff and the clinical support of the Southwest Research Consortium which includes the University of Texas Health Science Center in San Antonio. To identify particular problems

associated with evaluation and in order to gain experience that will contribute to the development of effective models, the REC solicits experimental/prototype products and technological devices from the rehabilitation community (both government-funded and commercially developed items).

Progress—REC activities have included engineering analysis and clinical evaluation of the Stanford Storable Crutch; wheelchair static loading tests conducted to prove draft testing methods proposed by the International Standards Organization; various demonstration evaluations to examine the validity of evaluation models; organization and management of a site visit team effort to determine the commercialization-readiness of a particular product; and some commercially-sponsored evaluation activi-

ties. Plans are in progress for a two-center clinical study of a Yugoslavian-developed functional electrical stimulation device for treatment of incontinence in women. An engineering and acceptance test procedure has already been developed and will be conducted prior to clinical investigations. Dissemination of program information has continued through the distribution of the Center's *TechEval* bulletin and additional publications, participation in conferences

and exhibits, visits to various resource organizations, and responses to numerous information requests.

Future Plans—Efforts to develop and refine evaluation plans and methods that will enhance product commercialization processes will continue. In addition, the Center will seek innovative applications for evaluation frameworks in the rehabilitation community.

Arm-Powered Bicycle for the Disabled

Douglas Schwandt, M.S.; Larry Leifer, Ph.D.; Peter Axelson, M.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Once the basic living needs are attended to, mobility and recreation become paramount to the complete rehabilitation and societal integration of an individual with a lower limb disability. Whether for recreation, sport, therapy, or self-powered transportation, bicycling is a popular activity providing many physical, psychological and social benefits. and bicycling is potentially as natural and revitalizing for the physically challenged as it is for the able-bodied. The availability of an arm-powered bicycle would extend mobility and exercise beyond wheelchairs to offer the dignity, the control, and the exhilarating freedom through movement associated with balancing and riding a bicycle.

Several companies market tricycles for children and adults, including an attachment which converts a wheelchair into a tricycle. The first arm-powered bicycle began as a VA sponsored student project in the Stanford University Mechanical Engineering Design Division during the 1979/80 school year. Development of successive prototypes continued at the RR&D Center, culminating in three distinct models: adult, child, and touring/racing. The arm-powered bicycle features drive, steering, and power input at the hand cranks. Adjustable

side casters smoothly touch down at the desired lean, and also fasten down for four-wheel maneuverability indoors. An optional folding crank tower facilitates transfer to and from wheelchairs.

Progress—The approach has been to design, build, and test successive prototypes, incorporating improvements, evaluating alternative configurations, and enhancing the manufacturability of the design. The fourth version, a pre-production prototype called the Para-Bike, was completed in Autumn 1982.

In Spring 1983, a company called Recreational Mobility, located near Eugene, OR, was incorporated to begin production of the Para-Bike. The product was renamed the Handbike, and three improved versions were marketed. Recreational Mobility is no longer producing the Handbike. However, a *Technology Transfer Manual* is currently being prepared at this RR&D Center to facilitate production of the Handbike by other potential manufacturers. New layout and detail drawings are near completion, using the computer-aided design facilities at the Stanford Center for Design Research. The drawings will be included in the *Technology Transfer Manual*.

Tandem Bicycles for Disabled and Able-Bodied to Ride Together

Douglas Schwandt, M.S.; Larry Leifer, Ph.D.; Peter Axelson, M.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Individuals with physical disabilities resulting from paraplegia, low level and incomplete quadriplegia, amputation, muscular dystrophy, multiple sclerosis, stroke, cerebral palsy, blindness, etc., who are endeavoring to live healthy and meaningful lives, can benefit greatly in their physical, psychological, and social well-being from participation in popular recreational activities.

A Tandem bicycle for individuals with and without disability would literally provide a vehicle for integrated mobility and recreation. On such a tandem, many who have been excluded from the revitalizing activity of bicycling will experience the freedom, exhilaration, and accomplishment of riding on two wheels.

As a spin-off from the development of the hand-propelled single-rider vehicle known as the Handbike, there is now a two-person version. A prototype of this first tandem bicycle for disabled and able-bodied to share, called the Handbike Tandem, was completed in June, 1983. The Handbike Tandem is, conceptually, a merging of a Handbike and a standard bicycle. In the interest of rider independence and equality, the tandem is designed so that it can be ridden by one rider alone in either the front or rear position.

Progress—The experience gained from the Handbike and the Handbike Tandem has led directly to the design of the new prototype called the Sunburst. Completed in June, 1984, it is designed to provide the physically-challenged with the many benefits of tandem bicycling.

Although similar to the Handbike Tandem in rider configuration, the Sunburst combines arm- and foot-powered recumbent cycling in the front with a standard bicycle arrangement in the back. The back rider steers through a

remote linkage from the handlebars to the front wheel, and pedals in a standard bicycling posture. The front rider sits in a recumbent position and powers with any combination of arms or legs. Both riders have a clear view ahead and find it easy to converse. The front cranks directly couple, allowing the front rider to assist or passively exercise his or her own less functional limbs. A freewheeling system allows the front rider to rest while the back rider continues to pedal and for those who prefer not to move their legs, a leg-rest attaches to the seat, so if a rider is unable to pedal at all, he or she may just go along for a ride. When the Sunburst comes to a stop, the front rider can lower a secure kickstand.

The front drive system and seat may be detached, yielding a single-rider bicycle. And to increase the market potential and to provide greater dignity for the disabled rider, the front position has been designed to appeal to able-bodied riders as well.

Future Plans—A *Technology Transfer Manual* is being prepared, documenting the tandem development, to facilitate transfer to potential manufacturers. Layout and detail drawings of an improved Sunburst II will be included. Near completion, these drawings have been generated using computer-aided design facilities at the Stanford Center for Design Research. Further performance and mechanical evaluations are needed to help assure that the most worthy tandem product will be available. In addition, collaboration is continuing with the builder of the Counterpoint (Counterpoint Conveyance Ltd., Seattle, WA), a similar tandem developed independently of the Sunburst. The intention is to combine the best of both designs.

Information Technology in Rehabilitation Engineering

R.E. Garrett, B. Tech., Grad. Dip. Maths., and B.R. Seeger, Ph.D.

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: *None Listed*

Progress—We have acquired an IBM look-alike computer with appropriate communications software to enable access to many rehabilitation systems now available. Important systems which are now accessible are: 1) ABLEDATA, a database on equipment for disabled people which is accessed through the Australian Overseas Telecommunications Commission system called MIDAS; 2) CONFER, an overseas information sharing system which is also accessed through MIDAS; 3) MINERVA, an Australian mailbox system with International and National Telex access; 4) DISCOM, a disability communication system operated by Prahran College of TAFE in Victoria (currently accessed by an STD phone call but soon to be accessible throughout Australia via AUSTPAC for the cost of a local telephone call); 5) Videotex Sys-

tems e.g. VIATEL, which gives access to banking, shopping, booking, etc.

The ability to download to and upload from a portable lap computer is also of importance in doing work at home. The future computerization of the information on equipment held in Independent Living Centres in Australia will be an important development.

In addition to the greatly enhanced information sharing available to rehabilitation professionals as a result of these developments, people with disabilities will benefit directly. A person without keyboard skills and unable to speak (i.e., unable to use the telephone) and perhaps unable to move easily outside their own home will have access to all of the above systems from home using an Apple IIe computer and Adaptive Firmware Card.

Technology to Enhance Independence of Physically Disabled School Children

Barry R. Seeger, Ph.D., and Ken Gransbury

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: *None Listed*

Purpose—A recent study has shown that the majority of children at the Regency Park Centre Special School experience problems with classroom skills, toileting, and mealtime activities which could be overcome by the application of appropriate technology. Our aims include: 1) investigation of the needs established in our earlier study of classroom independence, with a view to deciding whether the problems can be solved by commercially available technology, or modifications to existing products, or whether a new design is needed; 2) purchase of products which are available, and designing, building, and providing new solutions where necessary; and 3) measuring the extent to which the disabled child's independence has been enhanced by the application of new technology.

Progress—In the preliminary phase the priority problem areas established in our earlier study will be investigated. Where problems have ready-made solutions, those solutions will be implemented. Design guidelines will be established for the new designs which need to be developed. Priority will be given to the most cost-effective implementations of highest incidence. Toileting has been identified as an area of particular concern and importance, and our initial work will concern more independent and hygienic toileting. In the concluding phase followup measurements will be taken regarding the level of independence exhibited by children who have taken part in this project, in order to determine to what extent skills deficits have been compensated and independence has been enhanced through technological solutions.

Future Plans—This project will have an industrial designer working with the existing staff of doctors, engineers, teachers, therapists, nurses, and assistants to design and implement solutions for the problems we have identified that have high incidence and technological solutions. The expected outcome is that the children will be made more independent with cus-

tomized technological support, to the extent that some of them will be able to attend regular schools. The project will demonstrate how the introduction of technological innovations for physically disabled children in special schools and mainstream schools can improve the quality of their educational achievement.

Supported Employment

Barry R. Seeger, Ph.D., and Gary L. Wilson, B.Soc. Admin.
Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia
Sponsor: *Commonwealth Department of Community Services*

Progress—This project functions to give intensive training and support that will enable 15-20 unemployed severely disabled adults to participate in employment which is satisfying and provides for an equitable wage structure related to their work. S.A. Group Enterprises has

been established as a new joint venture initiated by Bedford Industries, Crippled Children's Association, and Minda Incorporated, and funded by the Commonwealth Department of Community Services, initially as a 12-month demonstration project commencing July 1986.

Rural Rehabilitation Technologies Database

Don V. Mathsen, P.E.; Doris M. Bornhoeft, M.S.; Charles M. Page
Energy Research Center, University of North Dakota; and Medical Center Rehabilitation Hospital, Grand Forks, ND 58202; with Community Medical Center, Missoula, MT 59801
Sponsor: *The Otto Bremer Foundation*

Purpose—Rural areas offer unique challenges to both the rehabilitation practitioner and the disabled individual. The development of rehabilitation technology traditionally takes place in "urban" centers. Meanwhile, "back at the ranch" individuals are developing their own solutions to problems they face daily. Each could benefit from the experiences of the other, and fellow consumers could benefit by not having to "reinvent the wheel" for themselves.

The purpose of this project was to catalog innovations, inventions, and ideas to benefit disabled persons living in rural settings. Work began in January, 1985; and the initial development of the projects has been completed. An update is planned for the winter of 1986.

Progress—A wide assortment of information was submitted and compiled into a 175-page

catalog. The catalog contains 100 entries in the area of "do-it-yourself" commercial products and resources. A Concept Paper section contains papers regarding "low-cost technology," computer databases, information centers, and the rural blind. The Future Plans section includes a registration form to be used by readers to submit ideas for future editions.

Requests for the catalog have been received from over 450 individuals, manufacturers, facilities, and organizations. These requests represent 47 states, the District of Columbia, six Canadian provinces, England, France, and India.

Future Plans—An updated version of the catalog will be developed and distributed to those who received the first edition and to those who sent requests after our supply was exhausted.

Interpersonal Problem-Solving by the Mentally Ill: Video-Assisted Technology for Training Social Skills

Clyde P. Donahoe, Ph.D. and Robert P. Liberman, M.D.

Brentwood Division, West Los Angeles, Veterans Administration Medical Center, Los Angeles, CA 90073

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to develop a videotape-assisted package for training veterans with psychiatric disorders in coping effectively with difficult interpersonal situations. The package is to consist of a videotape, a therapist's manual, and a patient's handbook. The training method is based on procedures from social skills training methodology, and the materials will be highly structured and detailed so that professional and paraprofessional staff in a variety of psychiatric rehabilitation settings can deliver the training.

The training will help patients to identify and articulate interpersonal problems, to generate possible alternative solutions, and to choose an effective solution to the problem. The training will also help patients to competently perform the solutions by learning how to use appropriate verbal and nonverbal social skills.

Progress—Progress has been made on the project to the point that a detailed script of the

final videotape has been completed, and production of the videotape will begin soon. A preliminary videotape has been completed, using a small sample of patients to test the procedure's effectiveness in helping the patients to acquire the targeted skills. Preliminary versions of the manuals have also been completed and are currently being revised for the final version.

Future Plans—Plans for the coming year include the production of other modules relevant to competent independent living (e.g., effective conversational skills, grooming, etc.). In addition, plans are under way to adapt the interpersonal solving module for use with veterans who have spinal cord injuries. It is hoped that, although the content needs of the module may be different for physically disabled veterans, the procedures we have originally developed for use with psychiatrically disabled veterans will be as effective for different populations.

Computerized Treatment of Acquired Reading Disorders

Leslie Gonzalez Rothi, Ph.D.

Audiology and Speech Pathology, Veterans Administration Medical Center, Gainesville, FL 32602

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Normal reading is dependent upon the integrity of at least two routes or functional systems, the phonological route and the lexical route. Dysfunction of either route results in alexia. The objective of our project is threefold: to develop therapy tasks suitable for improving deficient reading strategies associated with the lexical route or the phonological route; to develop computer programs for an interactive computer that would provide the patient with self-paced practice on the above tasks; and to assess the efficacy of these treatments when presented via computer interaction.

Progress—Each patient receives standardized pre- and post-therapy testing. Patient progress on each of the 6 tasks of therapy is monitored daily. Twelve subjects will be tested: 6 with deep dyslexia and 6 with surface dyslexia. Six tasks are presented to each patient in each subject group (3 directed at remediating the lexical route and 3 for the phonological route) during a total of 26 sessions. The tasks are presented via IBM PC/XT; and patient's responses are scored, analyzed, and stored on the computer. Five subjects have participated in the treatment thus far; however, none of the data will be analyzed until all 12 subjects have completed the project.

Therefore, no findings, results or conclusions are available.

Future Plans—Our goal for this research is to

develop computer programs for tasks of greater complexity for higher level alexic patients. Additionally, we hope to write programs for agraphic patients using a similar paradigm.

A Program for Evaluating the Dysvascular Patient

Bok Y. Lee, M.D., and Lee E. Ostrander, Ph.D.

Veterans Administration Medical Center, Castle Point, NY 12511, and Rensselaer Polytechnic Institute, Troy, NY 12181

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of Project I is to evaluate the role of lumbar sympathectomy in the management of patients with arteriosclerotic occlusive disease of the lower limbs. The purpose of Project II is to develop inexpensive and dependable instrumentation that is also reliable to clinically evaluate patients with vascular disease.

Progress—Project I. The role of lumbar sympathectomy in the management of patients with arteriosclerotic occlusive disease of the lower extremities remains a subject of considerable discussion. Much of the confusion concerning lumbar sympathectomy is due to a lack of procedures to accurately and sensitively select those patients in whom lumbar sympathectomy may be of benefit.

We have carried out a retrospective review of 101 lumbar sympathectomies to examine the role of a distal thigh (above knee)/arm systolic pressure index in selecting patients for lumbar sympathectomy. (Previously, we have established criteria using Doppler systolic ankle pressure, ankle-to-brachial systolic pressure ratio, external magnetic flowmetry measurements of peak pulsatile calf blood flow, and thermistor thermometry in selecting patients for lumbar sympathectomy.)

Preliminary Results—Of the 101 lumbar sympathectomies, 11 were excluded due to concomitant direct arterial surgery or being lost to followup. Data presented are thus based on 90 lumbar sympathectomies done on 82 male patients. Beneficial effects from lumbar sympathectomy were the relief of symptoms, the prevention of major amputation, or improvement

in disabling intermittent claudication. In these patients it was found that a Doppler systolic above knee/brachial pressure index of 0.60 or better, and an external magnetic flowmetry mean calf blood flow of 30 ml/min or greater, was found to be a good predictor of a beneficial effect from lumbar sympathectomy. These data are currently being prepared for publication.

Progress—Project II. Instrumentation being investigated is based on hydrogen clearance for perfusion measurement, tissue mechanical properties measured quantitatively by indentation, and cutaneous perfusion photoplethysmography for observing perfusion response to changes in tissue pressure. This work has focused on assessing peripheral vascular occlusive disease, chronic venous insufficiency, and tissue viability in pre and post-surgical patients.

Peripheral vascular occlusive disease is being evaluated by measurement of cutaneous perfusion pressure. A technique for local measurement of cutaneous perfusion pressures (CPP) has been developed which utilizes photoplethysmographic measurement during local pressure application to the skin. A total of 225 limbs have been studied to evaluate the usefulness of the method in detecting peripheral arterial disease and in differentiating disease severity. In a further study of 11 prospective amputees, CPP measurements were taken to determine the usefulness in evaluating amputees.

Preliminary Results—A significant decrease in CPP from the chest to the dorsum of the foot was seen in limbs with arterial disease, where the disease was evidenced by intermittent claudication, rest pain, and/or gangrene. The re-

sults indicate that the technique can successfully identify the presence of peripheral vascular disease, distinguish among different levels of severity, and aid in determining the optimal level of amputation consistent with wound healing. It can also assist in following the patient's course after reconstructive vascular surgery.

With respect to chronic venous insufficiency, one finds that it often impairs patient mobility, but that it is difficult to assess due to the lack of objective, noninvasive, and routinely useable clinical tests. To improve assessment, we have developed a test for quantitative measurement of venous reflux and for separate identification of deep and superficial involvement. The test is noninvasive and requires minimal patient cooperation. The total venous reflux measurement system uses an inflatable boot placed over the lower limb from foot to below the knee, in the seated subject. The boot is inflated to 60 mm Hg., and calf volume is measured by impedance plethysmography when the boot pressure is abruptly released, allowing blood to return to the limb. Changes in impedance with time measure the rate of change in

volume and therefore blood flow. To obtain a separate measurement of deep venous reflux, a tourniquet is placed above knee to impede flow through the superficial system, and the test is repeated. To calculate superficial reflux, one subtracts deep reflux from total reflux.

Evaluation of the method was carried out in a series of 89 limbs. A grouping of 35 limbs according to venography findings showed that the test of total reflux provided a differentiation of patients according to the presence of primary and/or secondary varicosities. The superficial reflux measurements provided a further differentiation of patients afflicted with primary varicosities.

Future Plans—Other studies under development and in progress relate to the measurement of perfusion with the use of fluorescein fluorometry and noninvasive hydrogen clearance. This work is proceeding in animal studies of bowel function as related to perfusion and in approaches to fluorometry which reduce risk of patient reaction to dye administration.

Training Schizophrenic Patients in Medication Management

Robert P. Liberman, M.D., and Thad A. Eckman, Ph.D.

Brentwood Division, West Los Angeles Veterans Administration Medical Center, Los Angeles, CA 90073

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Previous studies have indicated that skills training procedures can be an effective approach to treating patients with chronic mental illness. The Rehabilitation Medicine Service at the Brentwood Division of the West Los Angeles Veterans Administration Medical Center, in conjunction with the UCLA Department of Psychiatry and Camarillo State Hospital, has been developing and evaluating a highly structured (modular) approach to skill training. A series of modules, each composed of a trainer's manual, a demonstration videotape, and a patient workbook, are in varying stages of development and production. One of these, the Medication Management Module, has been evaluated in the Social and Independent Living Skills program at the Brentwood Veterans Ad-

ministration Medical Center.

Progress—At the present time, a study is being conducted to determine whether mental health professionals working in a diversity of settings can learn to use the module with minimal training and supervision. This question is currently being addressed in a large-scale field test of the module throughout the United States and Canada. The primary objective of the field test is to document the efficacy of the module, with a large number of patients taking neuroleptic medications, before the module materials are disseminated on a nationwide basis. Currently in progress, the field test is expected to yield information regarding user-friendliness, trainer competence, and impact on patient

knowledge of, attitudes toward, and use of antipsychotic drugs.

Additionally, questions related to the amount of training required to attain minimal levels of trainer competence will be answered.

Twenty-eight field test sites have been randomly assigned to each of two conditions (training plus consultation versus consultation alone). The sites represent a wide geographic distribution and a broad range of inpatient and partial-hospitalization programs located in public and private psychiatric hospitals, community mental health centers, and residential care facilities. Expert consultation has been available by telephone throughout the field test for all sites.

In the field test, therapist competency is measured in three domains: knowledge of module content and procedures (cognitive mastery); the ability to accurately and consistently follow procedures specified in the therapist's manual (behavioral mastery); and the ability to assess a patient's progress accurately.

The impact on patients participating in the field test is evaluated in three domains: compli-

ance, knowledge, and skills.

Preliminary Results—Preliminary findings suggest that medical practitioners and others in the Allied Health profession find the module materials and training procedures relatively easy to use and effective with patients. The prescriptive nature of the trainer's manual combined with the availability of expert-consultation, has made it possible for users to implement the module procedures without the benefit of extensive training. It should be noted, however, that a fidelity study suggests that some training may be required to achieve an expert level of proficiency.

In terms of the impact that the Medication Module has on patients participating in the study. Results from the first field test sites to complete the study portend significant gains in cognitive mastery and a relatively high level of skill attainment among patients. Results related to medication compliance and skill maintenance in patients must await the followup phase of the study.

Training Chronic Mental Patients in Social and Independent Living Skills

Robert P. Liberman, M.D., and Thad A. Eckman, Ph.D.

Brentwood Division, West Los Angeles Veterans Administration Medical Center, Los Angeles, CA 90073

Sponsor: VA Rehabilitation Research and Development Service

Progress—For more than 4 years, the Rehabilitation Medicine Service in the Brentwood Division of the West Los Angeles Veterans Administration Hospital, in cooperation with the UCLA Department of Psychiatry and Camarillo State Hospital, has been developing and evaluating the Social and Independent Living Skills series of highly structured training modules to teach social adaptation and foster rehabilitation in chronic mental patients. The modules are being designed to be used as part of a comprehensive treatment program that includes antipsychotic drugs, family therapy, and case management.

The modules provide detailed, step-by-step instructions, and can be used by health care professionals who have experience working

with patients with chronic mental illness. The trainer or therapist teaches the skills using a combination of videotaped demonstrations, focused instructions, specialized roleplays, social and videotaped feedback, and practice in the patient's natural environment.

Patients with schizophrenia or other chronic disorders can learn needed skills with these training strategies. A number of studies carried on during the past decade in the United States, Italy, and Switzerland indicate that patients who receive training in social and independent living skills demonstrate improved social adjustment and have fewer relapses.

The modules are being developed and evaluated by an interdisciplinary team of clinical researchers and rehabilitation specialists. Ulti-

mately, 12 modules will be produced. The modules, which are in various stages of design and production, include: Medication Management; Leisure and Recreation; Selfcare and Grooming; Conversation Skills; Symptom Management; Social Problem Solving; Friendship and Dating; Food Preparation; Money Management; Home-finding; Transportation; and Using Community Agencies.

Each module provides a highly prescribed protocol with three components: a trainer's manual, which contains both a comprehensive overview of the module and instructions sufficiently detailed to enable quick assimilation and use; a videotape, which demonstrates the desired behavioral skills for patients; and a patient's workbook, which provides reinforcement for the contents of the module and documents the patient's participation.

Preliminary Results—The first module to be produced, Medication Management, is presently available through McNeil Pharmaceutical. Trials of this module have shown remarkable success. Improvement from baseline scores (mean percent of behavioral skills observed in roleplay tests) ranged from 37 percent to 65 percent after training; erosions of only 7 percent to 12 percent in skills were noted at 3-

month followup assessments.

In other controlled trials of the problem-solving method of teaching social skills, improvements persisting for as long as 2 years were documented. Since these evaluations were made at places and times apart from the training sessions, these results indicate durability and generalization of the knowledge acquired.

The Medication Module is presently being field-tested in 30 hospitals and mental health centers throughout the United States and Canada. It is published in final form and ready for distribution.

The Leisure and Recreation Module was evaluated in the Social and Independent Living Skills Program in the Rehabilitation Medicine Service at Brentwood VA Hospital and will be field-tested during the coming year.

The Symptom Management Module is nearing completion and will be formally evaluated in the Social and Independent Living Skills Program in the fall of 1986.

Future Plans—Other modules scheduled for completion during the next year include Self-care and Grooming and Social Problem Solving. With continued funding, 2 modules per year will be readied for dissemination until the entire series is completed.

Dissemination of Rehabilitation Technologies

Alvin H. Sacks, Ph.D., and Robert A. Weisgerber, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Although we often read about new technologies being applied to or developed for use by disabled individuals, relatively few such technologies ever result in a specific rehabilitation product, and fewer high-technology products are available to the disabled community at large. The reasons for this situation are complex and have not been studied in depth.

It is clear that even well-designed devices developed for use in the disabled community suffer from a number of factors which mitigate against their successful dissemination to the end user. From a commercial point of view, the

market is small, the devices are often expensive, and most of the potential users do not have much money to spend. Consequently, costs must usually be recovered from third party payers, which introduces certain bureaucratic complications.

The central hypothesis of this study is that user acquisition and utilization of innovative rehabilitation technology could be improved if the system which researches, develops, manufactures, delivers, and maintains that technology were better understood. It is expected that this increased knowledge would permit identifi-

cation of factors in the rehabilitation technology transfer process that can be modified in order to facilitate the delivery of rehabilitation technologies to targeted populations.

Progress—A contract was awarded by the Veterans Administration to American Institutes for Research (AIR) in the Behavioral Sciences, in early January, 1986. The contract calls for a study of the problem from a viewpoint that is alert to opportunities for developing appropriate strategies for the successful dissemination of rehabilitation technologies.

Meetings have been initiated between technical staffs of the Institutes and the Rehabilitation Research and Development Center, and the program will be carried out as a joint effort. Questionnaires are now being formulated as the first step toward studying selected rehabilitation devices which have or have not been successfully disseminated to the intended users with various disabilities.

Future Plans—In its initial stages, researchers will seek to identify instructive examples from

the history of rehabilitation technology transfer. A case study approach will be used to investigate these examples: questionnaires will be generated for evaluators, trainers, and users; interviews will be conducted with principals; and original documentation will be sought. On the basis of these studies, investigators will attempt to identify the factors that facilitated the successful transfer of technology, along with those that hindered. A comparison of the case studies will provide a list of common problems, together with a suggestion list of strategies for dealing with them.

The second stage of the project is expected to involve attempting to validate these strategies, and to prioritize them according to feasibility and effectiveness. This will require implementation of partial strategies, where possible, through collaboration and interviews with current researchers, manufacturers, trainers, third party payers, and others.

In the third year, findings from this work will be published in monograph form, available for distribution to interested parties.

Development of a Life Satisfaction Scale Applicable for People with Severe Disabilities

Steve Shindell, Ph.D.; Gregory L. Goodrich, Ph.D.; Michael Dunn, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: *Veterans Administration Rehabilitation Research and Development Service*

Purpose—This study seeks to develop a clinically useful structured interview that will provide insight into the adjustment process of people with various disabilities. The goal is to refine the structured interview into a quick, inexpensive, standardized clinical assessment device that will measure the perceived life satisfaction (quality of life) and coping skills of people with a variety of severe disabilities. We will also attempt to validate the structured interview with a longitudinal study of individuals enrolled in several different inpatient rehabilitation programs at the Palo Alto VAMC (Western Blind Rehabilitation Center, Spinal Cord Injury Center, and Rehabilitation Medicine Services), and with a matched comparison sample of non-

disabled veterans.

Work on this project began in 1984 when the principal investigators developed a preliminary version of the structured interview, based on several adjustment scales currently in use in various rehabilitation settings. That preliminary version represented a substantial improvement over other assessment devices in that it was designed for general use with any disability group, it included measures of actual behavior and activities of daily life, and subjective appraisals of quality of life were directly solicited. The structured interview was dubbed 'The ACCESS Questionnaire' (Assessment of Current Community, Emotional, and Social Satisfaction) and administered (at intake, discharge, and 6

months post-discharge) to a pilot sample of 30 individuals undergoing blind rehabilitation.

Progress—The ACCESS Questionnaire has gone through two revisions since the first pilot version was tested. Ninety patients at the WBRC completed all 3 assessments (intake, discharge, and follow-up) with the first revised form, and preliminary analysis of the data from those individuals led to a second revision of the questionnaire, which is now in use at all three rehabilitation centers. To date, the Access Questionnaire has been administered to well over the planned 100 patients at the WBRC. New patients are no longer being routinely included in the study because we project that continued follow-up should yield more than 150 patients. However, we are continuing to include all women and members of racial minority groups in order to increase their representation in our sample.

Because of a delay in the planned expansion of the Spinal Cord Injury Center, we have obtained only about 25 percent of the number of these patients we had anticipated. Efforts are underway to expand our sample of spinal cord disabled individuals by cooperating with the Spinal Cord Injury Unit at the Santa Clara County Valley Medical Center. We have also collected only about 25 percent of the planned number of individuals from the general Rehabilitation Medicine Ward. However, we have already administered the Access questionnaire to 116 nondisabled veterans, and to about 33 percent of the planned number of 5-year-posthabilitation samples.

Preliminary Results—Preliminary analyses of the data are under way, and there are several interesting tentative findings. First, it is clear that patients undergoing rehabilitation at the project centers report a significant improvement in their life satisfaction over the course of their stay (the percentage reporting only fair or

poor life satisfaction decreases from about 35 percent to under 20 percent, and the percentage reporting very good or excellent life satisfaction increases from about 30 percent to more than 50 percent).

Second, these improvements in overall life satisfaction are maintained with little or no deterioration throughout the 6-month period following discharge from the rehabilitation center.

Third, although the quality of life of our disabled subjects improves considerably as a result of their rehabilitation, it remains significantly lower for many of them than the quality reported by our non-disabled matched comparison sample of VFW members (only 7 percent of whom report poor or fair quality, while more than 60 percent report very good or excellent quality).

It is encouraging to note that a separate study of the reliability and interjudge-agreement of our project interviewers establishes that it is possible to obtain very high reliability with the ACCESS Questionnaire. The mean intercorrelation (r) across the quantitative items on the questionnaire was .78, and the overall percentage agreement across all items and all raters was 79.4 percent (an additional 19.1 percent were only off by 1 point on a 5-point scale).

The ACCESS Questionnaire is currently also being used at the Low Vision Clinic of McGill University in Montreal, and at the Eastern Blind Rehabilitation Center in West Haven, Connecticut.

Future Plans—In the coming year, we will work to complete our samples of disabled individuals, and will proceed with a planned effort to develop subscales of the ACCESS Questionnaire that are clinically relevant, theoretically interesting, and that furnish reliable indices of various discrete aspects of the quality of life of disabled individuals. We will also continue to share the efforts of our work with the broader clinical and research community.

Rehabilitation of Neurogenic Communicative Disorders in Remote Settings

Robert T. Wertz, Ph.D.; Jon L. Deal, Ph.D.; Robert T. Knight, M.D.; Gregory K. Shenaut, Ph.D.

Veterans Administration Medical Center, Martinez, CA 94553, and Veterans Administration Medical Center, Des Moines, IA 50310

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—Many patients who suffer neurogenic communicative disorders reside where services are not readily available. Either these patients are not managed, or they must travel long distances to receive services, or they must remain or become inpatients for extended periods to receive services. Developing a means to deliver services in remote settings would provide management for patients who currently do not receive it; reduce the inconvenience and cost of travel; eliminate the necessity and cost of hospitalization; eliminate the cost of contracting services from private practitioners; and eliminate the high expense of developing additional classic treatment programs.

Progress—We are conducting an investigation designed to determine whether an existing appraisal and treatment center can utilize technology to provide management of neurogenic communicative disorders in patients who reside in remote settings. Three appraisal conditions are being compared: traditional face-to-face evaluation; appraisal in a closed-circuit television condition where the patient and clinician can see and hear each other; and appraisal in a telephone condition where the audio signal is

transmitted through speaker-phones; visual stimuli are sent over a phone line and displayed on a touch-sensitive video screen connected to a computer-controlled video laser disc, and writing is transmitted over a phone line and reproduced by a TELENOTE transcriber.

Patients participating in the appraisal study display aphasia, dementia, dysarthria, apraxia of speech, and combinations of these disorders. In addition, a treatment trial is being conducted with aphasic patients who meet selection criteria. Patients are assigned randomly to one of three conditions for treatment: face-to-face, television, or video laser disc.

The investigation was initiated in July 1984 and is designed to be completed in July 1987. Currently, data are being collected in the VA Medical Center, Martinez, CA, where we are simulating delivery of services in remote settings.

Future Plans—If the initial results are positive, the investigation will be replicated in a field test in two VA Outpatient Clinics where management of neurogenic communicative disorders is not available.

A Manual for the Development of a Program in Rehabilitation Medicine in a Ghetto Hospital

Albert D. Anderson, M.D., and A. David Gurewitsch

Rehabilitation Medicine, Columbia University — Harlem Hospital Center, New York, NY 10037

Sponsor: *Columbia University College of Physicians, with Harlem Hospital Center*

Purpose—The Department of Rehabilitation Medicine at Harlem Hospital plans to publish a manual of instruction on the development of a rehabilitation program in an urban setting for the deprived and the poor.

The Department now has at least seven programs for students in multiple disciplines of Rehabilitation Medicine, including a training

program for physicians and one for health workers from the community. The goal is to provide a didactic multidisciplinary methodology for the building of a rehabilitation program from the moment of funding.

Progress—The program manual is divided into six sections dealing with the ecology of poor

areas, the physical modalities and the peculiar methods or patterns of administration necessitated by the needs of the client population; the sociology of poverty and psycholinguistics problems encountered in the population surrounding a hospital providing care to a deprived minority; and restorative care to the impaired child in an urban setting.

An instruction manual of this sort requires an extensive description of nursing in its multiple roles within a health facility.

The manual ends with an extensive de-

scription of electrodiagnostic problems (drug neuromyopathy, sequelae of trauma, neurological disorders resulting from infections) that should be anticipated. Although multidisciplinary in its target student population, the manual closes with instructions addressed to the physician on how to play the advocate role.

The text is provided in a hardcover ring binder that permits students to insert the notes and loose material distributed in various sections, through which they rotate.

Diabetic Neurotrophic Ulceration: Screening and Prevention Utilizing Aesthesiometry

John J. Holewski, D.P.M.

Veterans Administration Medical Center, San Francisco, CA 94121

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Development of neurotrophic ulceration in the diabetic patient leads to amputation of limb and disability of these patients. Currently, most information and effort is directed at treatment of the already formed neurotrophic ulceration. Information is known on prevention, but effective methods for quantitating the overall status of the diabetic foot are lacking. New criteria are needed for the variables which cause ulcer formation. This study will focus on peripheral neuropathy and its relationship to the diabetic's loss of protective sensation leading to ulceration.

It is proposed that Semmes-Weinstein aesthesiometry measuring cutaneous touch pressure sensation could be an effective, practical method for quantitating the extent of peripheral neuropathy in the lower extremity of diabetic patients. New criteria utilizing aesthesiometry can be established that can assist in the diagnostic process to predict the relative risk of development of neuropathic foot ulceration in the diabetic population.

This project will follow 100 diabetic patients divided into three risk groups of equal size: low, medium, and high on the basis of cutaneous touch sensation. These patients will be followed with noninvasive screening tests 3 times annually, in addition to their regular rou-

tine foot care.

This proposed project is a survey of a patient population; no alterations in patient treatment will be done. The screening tests will include cutaneous sensation testing, a photograph of the plantar surface of the foot to document lesions and foot structure, and completion of a history/physical questionnaire which will be used as a database.

The database will be analyzed by Clinfo statistical packages on the station-wide PDP 11/24 computer, especially noting changes in cutaneous touch sensation and occurrence of ulcerations. Data will be evaluated to determine if cutaneous sensation is an effective parameter for division of risk groups. Each group will be evaluated to determine what other variables cause differences within the group. In addition to determining the efficacy of aesthesiometry in quantitation of peripheral neuropathy, this analysis of the database will provide a clearer understanding of the variables of ulcer formation as related to peripheral neuropathy.

Clinically, this information can be used to enable one to intervene with appropriate treatment or preventive measures to control or prevent occurrence of diabetic neurotrophic pedal ulceration.

Thermographic/Spectroscopic Comparison of Soaks, Exercise, and Trental™ on Diabetic Feet

Kathryn M. Moss, D.P.M.

Veterans Administration Medical Center, San Francisco, CA 94121

Sponsor: *Rehabilitation Research and Development Service*

Purpose—Diabetic foot ulcers, through infection and nonhealing, cause significant disability and limb loss in an expanding diabetic population. Multiple factors, i.e., vascular insufficiency, neuropathy, metabolic abnormalities, and structural deformity, have been investigated as contributing to tissue breakdown in the diabetic foot. However, the relative role of each of these factors is unclear. Thus far, no specific criteria have been established to assess the progress of diabetes-related foot diseases. It would seem both financially and medically prudent to develop noninvasive diagnostic tests to identify patients who are “at risk” of ulceration in order to facilitate the earliest medical intervention.

The objective of this project is to delineate any thermographic or spectroscopic differences within the diabetic population that could be used to screen out patients “at risk” of ulceration.

Future Plans—Using liquid crystal thermography and magnetic resonance spectroscopy, this project will study vascular reactivity in skin and the level of ischemia in muscle in the face of various therapeutic maneuvers. This project will evaluate 40 patients equally divided

into 4 population groups. Each patient will be interviewed, and a standard questionnaire covering pertinent medical history will be administered along with a physical examination of the foot. Based on this information, patients will be placed in one of four study groups: 1) nondiabetic controls; 2) diabetic patients with no prior history of foot ulceration; 3) diabetic patients with a prior history of foot ulceration but without active foot ulcers; and 4) diabetic patients with active foot ulceration.

Thermographic evaluation of all patients will be completed before and following three different therapeutic maneuvers: 1) exercise; 2) uniform warming; and 3) an 8-week therapeutic trial of Trental™. Magnetic resonance spectroscopy will be completed on a smaller set of patients distributed among the groups, but evaluating only exercise and Trental™.

The database will be analyzed using the Clinfo statistical package to determine how one population differs from the other and how exercise, warming, and Trental™ affect thermographic and spectroscopic patterns. It is hoped that this information will aid in the development of a prospective index in the overall assessment of the diabetic foot.

Development of a Sensory Substitution System for the Insensate Foot

Jacqueline J. Wertsch, M.D.; Paul Bach-y-Rita, M.D.; Melvin B. Price, D.P.M.

Veterans Administration Medical Center, Milwaukee, WI 53193

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The main objective of the research is to develop a practical sensory substitution system for the foot.

In the first year, we will develop an excitation and amplification system for the chosen commercially-available pressure transducer. We will work out the mechanism for installation of the transducers into a silicone rubber insole.

Hardware and software for a microcomputer signal-processing system will be developed to acquire the pressure data, process it, and use it to drive a display system, which will be a modified commercially-available device. Spatial sensitivity of the pressure transducer and electro-tactile display will need to be measured. A radiotelemetry system will be developed.

When we are satisfied that the design and function are correct, we will construct trial systems for evaluation. The systems will be tested by using 2 normal subjects. Normal subjects are being used to test the durability of the system and the usefulness of the data acquired. It is projected that at least 1 of the normal subjects will be 1 of the investigators.

During the second year, utilizing data from the initial clinical evaluation, we will improve the electronics for a lower power, more compact system; write additional software for signal processing; and build 4 additional systems for clinical evaluation. Especially valuable will be the feedback regarding the subject's ability to interpret the information.

During Years 2 and 3, 4 patients with insensate feet will be used to evaluate the device. High risk patients from the Podiatric Medicine Clinic with additional biomechanical risk factors will be chosen. They will represent the insensate foot with a plantarflexed second metatarsal, with forefoot varus, and with plantar-

flexed first metatarsal. One blind diabetic with insensate feet will also be included. With the feedback from these subjects, further development of the microcomputer software will be possible. During the third year, utilizing data from the Year 2 clinical evaluations, we will attempt to simplify the signal processing, modifying the \$5 commercial pressure transducers to lower cost. We will build 4 additional systems for clinical evaluation, evaluating all data to determine if fewer than 7 pressure transducers can provide sufficient sensory feedback. Modifications may be possible in the number and placement of transducers. We will evaluate alternative electrode materials for use in the electrotactile display, seeking a less expensive display system than the current modified commercial system.

Future Plans—The long range goal of this project is the development of a functional, economical, and cosmetically acceptable sensory substitution system.

Information Resources

Sara Brandenburg, M. S.

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, Madison, Wisconsin, 53705

Sponsor: *National Institute of Handicapped Research*

Purpose—The Trace Center, which has published an updated version of the Non-Vocal Resource Book, is currently working on the Rehabilitation Resource Book Series, a set of 3 books describing nearly 1000 products available for disabled individuals in the areas of communication, control, and computer access. Each volume also contains reference materials and a variety of application tips relevant to the theme of the book.

Each of the three volumes will include a comprehensive index and cross reference by function, input, and output features.

Progress—The Rehabilitation Resource Book Series will be available from College-Hill Press in the fall or winter of 1986. (A database was generated to store and track product informa-

tion for updates of these books.)

Requests for information received by Trace Center have been handled through a variety of resources. When possible, information is provided through preprinted materials available either through the reprint service or through specially developed information resource sheets. During the past year, information sheets (Trace Quick Sheets) were developed or updated for 16 different areas, and 3 reprint articles were also updated.

When use of written materials is not possible, members of the information project staff answer questions through telephone and written responses.

Future Plans—Monthly 2-hour open houses are held for visitors. These provide information re-

garding center projects and demonstrations of current computer-access and alternative communication methods. Future plans are also described and demonstrated.

Future plans include establishing new

channels of information collection and dissemination, including participation in on-line databases, bulletin boards, and networks. Continued participation in conferences and workshops is also planned.

HSRI Mental Health Strategic Planning and Resource Allocation Model

H. Stephen Leff, Ph.D.

Human Services Research Institute, Cambridge, MA 02140

Sponsor: *Human Services Research Institute*

Purpose—The Human Services Research Institute (HSRI) has developed and implemented a microcomputer-based system for mental health strategic planning and resource allocation, the MHPLAN. MHPLAN helps decisionmakers select the most cost-effective mix of services for their mental health system.

The MHPLAN system includes functional level assessment instruments, service planning and cost estimation spreadsheets, manpower planning spreadsheets, and simulation models for projecting service system costs and effectiveness. Input to all system components can be varied to reflect local factors and judgments.

Progress—MHPLAN programs have been developed to work in the context of LOTUS 1-2-3™ software and with most IBM™-compatible hardware. MHPLAN's LOTUS™ context permits information to be readily provided in tabular and graphic form.

MHPLAN has been field-tested with the

chronically mentally ill adult population in a number of states. HSRI is now under contract to develop and apply versions of MHPLAN to children with chronic and severe mental illness and to persons with serious substance abuse disorders. HSRI also has contracts to apply MHPLAN for human resource planning.

Future Plans—In the near future HSRI will adapt MHPLAN for use with the elderly population. HSRI makes the MHPLAN system, including software, available as part of a strategic planning and resource allocation technical assistance consultation. Ongoing consultation is available for 1 year beyond the basic consultation. HSRI is a nonprofit organization that specializes in developing methods and information for planning and evaluating services to persons with chronic and severe mental illness and persons with developmental disabilities. Most MHPLAN funding is derived from contracts with state departments of mental health.

Social Skills Training for Older and Younger Persons with Severe Physical Disabilities

Pamela Finnerty-Fried, Ph.D., C.R.C.

The George Washington University Medical Center, Department of Psychiatry & Behavioral Sciences, Washington, D.C. 20037

Sponsor: *National Institute of Handicapped Research*

Purpose—In the area of rehabilitation services, certain attitudinal barriers between people with disabilities and those with whom they interact may present serious obstacles to the progress of an individual's rehabilitation and to the overall feeling of well-being. In many in-

stances, attitudes of employers, family members and friends may be more crucial to rehabilitation than physical restoration, training, or other services. The current project seeks to provide disabled people with tools they can use to overcome certain types of attitudinal barriers

which they may encounter and to interact more effectively in a variety of social situations.

Becoming disabled frequently entails having to cope with a variety of interpersonal issues. Among these are dealing with negative attitudes, having to request help or refuse unneeded assistance, and making overtures to nondisabled individuals who may be uncomfortable with one's disability. The Social Skills Training Program addresses interpersonal concerns raised by disabled persons of a variety of ages.

Progress—Modeled after assertiveness training programs, the program focuses on specific interpersonal skills which were identified by a panel of disabled persons as being particularly important and/or stressful. The skills are: asking for help, refusing unneeded help; coping with embarrassing situations; establishing new relationships; and job maintenance and advancement skills. These skills were seen as important by a panel of disabled persons in the younger (20-40) and older (45-65) age ranges.

Subjects are recruited and randomly assigned to social skills training or stress management, the alternate treatment. Pre-test, post-test, and six-month follow-up measures include the following: 1) Issues in Disability Scale (IDS); 2) Acceptance of Disability Scale (AD); 3) Adult Self-Expression Scale (ASES); 4) Interpersonal Situations Survey (ISS) (developed by project staff); 5) self-report of interpersonal effectiveness (developed by project staff); 6) IDS sent to people in social support system identi-

fied by trainees.

The instruments are designed to assess outcomes in the areas of attitudes toward self and disability and effectiveness in social situations.

The trainers include disabled persons, as the modeling effect is considered to be critical. The training programs are committed to a training manual, which will be available for dissemination. All sessions are audiotaped and monitored for adherence to the program.

To date, approximately half of the subjects have completed the training at either the Maryland Rehabilitation Center or in the Counseling Laboratory at George Washington University, a community setting. Follow-up assessments have been conducted on one-third of those who completed the training. The sample has included both older and younger persons, as skill acquisition is considered to be important at different stages of an individual's career; and there is a dearth of information on older rehabilitation clients. Preliminary analyses are currently being conducted.

Future Plans—The remainder of the project period will be devoted to completing data collection and analysis. In addition, dissemination of the packages to rehabilitation settings will be conducted. The training program has been designed for use by persons with a wide range of training and could be useful in peer counseling programs in rehabilitation centers, school settings, community settings, and in vocational rehabilitation programs.

Family Factors and Work Adjustment of Handicapped Mexican-Americans_____

Bill R. Arnold, Ph.D.

Department of Psychology, Pan American University, Edinburg, TX 78539

Sponsor: *Field Initiated Research Program, National Institute of Handicapped Research*

Purpose—There exists a paucity of quality research describing unique Hispanic cultural factors, such as machismo, la palabra, la familia and overprotectiveness, which influence the vocational rehabilitation process. Over a 36-month period, this south Texas research project will describe patterns of Mexican-American

family interaction, and family member attitudes toward rehabilitation resource utilization for bilingual, bicultural, vocationally handicapped Mexican-Americans.

All handicapped individuals (potential subjects) will have been: 1) mentally stable; 2) eligible for vocational rehabilitation services by the

Texas Rehabilitation Commission; and 3) determined to be bilingual and bicultural prior to selection as a subject. After 3 and 6 months of vocational rehabilitation services, data will be analyzed to identify culturally relevant family predictors of the development of competencies which promote attainment of vocational potential and work adjustment.

Progress—After initial identification by Spanish surname, referral to the study by State agency counselors, and signing a release of confidential information and agreement-to-participate form, a bilingual research assistant administered: 1) the Acculturation Rating Scale for Mexican-Americans; 2) a personal data sheet developed by the authors; 3) the Family Environment Scale; 4) the McCarron Dial Evaluation System; and 5) the Perceptual Memory Task. Each instrument was administered in the preferred language of the subject, English or Spanish. By June 1986, a total of 47 subjects have been initially evaluated, with 31 having been reviewed at a 3 month followup; and 15 of these subjects were reviewed at 6 months. During April 1986, a preliminary analysis of 43 subjects explored the relationship between

Mexican-American level of acculturation, educational level, age, family size, and family interaction patterns. This initial analysis focused only on providing a preliminary descriptive analysis of patterns of family interaction among bilingual, bicultural Mexican-Americans, as provided by the disabled family member. The results of that study were presented at the annual conference of the National Association of Rehabilitation Research and Training Centers in April 1986.

Future Plans—Further analyses on the verbal-cognitive, sensory, and neuromuscular data will be forthcoming when followup data is completed at the end of year 1986. As a result, during Year 3 of the Project, a culturally-sensitive Family Interventions Manual for Handicapped Mexican-Americans will be developed for modifiable factors, based on social learning theory and principles of operant learning, which promote patterns of family interaction and/or attitudes that facilitate the maintenance or development of the previously identified work adjustment competencies. The results of the research also will be disseminated regionally and nationally during each year of the Project.

Laser Removal of Tattoos and Port Wine Stains

J.H. Evans, Ph.D., and W.H. Reid, F.R.C.S.
University of Strathclyde, Glasgow G3 ONW, Scotland
Sponsor: Scottish Home and Health Department

Purpose—Clinical trials of the use of lasers to remove tattoos and Port Wine Stains are well advanced. The techniques are both based on the selective absorption of energy and optothermal conversion where peak temperature distribution is governed by the pulse length (duration of irradiation).

Progress—In tattoos, the most common and obvious chromophores (pigments) are carbon-based or blue/green. The skin is naturally most transparent in the red and near infrared regions of the "visible" spectrum, whereas the tattoo pigments are absorbent. A Ruby laser (694 nm) is currently used but the ND:YAG

laser is a rational alternative. The laser is Q-switched to give a pulse length of 30 ns. Based on a 5 mm diameter light spot, this provides the desirable power density of 3 Tw/m². Usually a local anaesthetic is administered with a vasoconstrictor, and 4 exposures at monthly intervals are typically required to eradicate tattoos. The epidermis is not disrupted, and dermal scarring is not normally apparent. Accidental tattooing, such as pigmentation arising from close-range firearm discharge, as well as decorative tattoos, can be treated; but irradiation of coal dust within the dermis can result in epidermal rupture.

Port Wine Stain haemangioma are being

treated using a pulsed dye laser tuned to 577 nm and 300 μ s pulse length. The blood in the

aberrant vessels acts as the target and thermal denaturation extends to the perivascular tissue.

The Research and Training Center on Independent Living (RTC/IL)

James F. Budde, Ed.D.

The Research and Training Center on Independent Living, University of Kansas, Lawrence, KS 66045-2930

Sponsor: *The Research and Training Center on Independent Living*

Purpose—The mission of the Research and Training Center on Independent Living (RTC/IL) is to develop and disseminate practical techniques that enable people with severe disabilities to live more independently. These new technologies include service delivery systems and skill training methods that improve social services and community support for people with disabilities.

RTC/IL is devoted exclusively to independent living. Our foremost constituency is the network of more than 300 independent living programs throughout the country and the people they serve. Estimates indicate that each year these programs provide direct services to over 140,000 disabled individuals.

Progress—Specific research and training activities for 1986 are:

1) **Promoting Consumer Involvement:** Teaching consumers with severe disabilities new ways to improve their community and its services is a promising approach to independent living. In the past 4 years, Stephen Fawcett and colleagues have developed and evaluated the Concerns Report Method. This unique self-help method allows disabled citizens and their families to assess, prioritize, and convey their concerns to decision makers.

To date, over 2,500 disabled residents have used the Concerns Report Method to establish priorities for independent living services.

2) **Involving Disabled Consumers in Community Change:** Many community decisions affect individuals with disabilities and their families. For disabled persons to achieve equal opportunities, they must assume leadership roles in their communities.

Project staff have prepared self-help guides on how to identify, select, report, and discuss

issues; lead group discussions; and take action on issues. Procedures for establishing effective consumer groups and training current and new members have also been prepared, evaluated, and disseminated to interested consumer groups.

3) **Training Attendant Care Management Skills:** Attendant care is a vital service for many people with severe disabilities who live independently. Until now, there has been no empirically based model for teaching consumers how to train and manage an attendant.

Project staff are currently developing complementary materials for agency staff so they can implement consumer training in their own settings. (Plans for next year include field testing the complete procedures package in two settings).

4) **Encouraging Courteous Service Provision:** People with disabilities frequently must deal with human service agencies, such as local welfare offices, that can be insensitive to their needs. From applications of the Concerns Report Method, we have identified a perceived lack of courtesy and responsiveness in service provision as a major concern of people with disabilities.

5) **Promoting Community Support for Independent Living:** A top concern for independent living technology development is how to enlist community support for issues related to independent living. Most Independent Living Centers (ILCs) agree that it is essential to gain community support and that their current efforts could be more successful.

A self-help guide is being prepared to allow ILCs to prepare slide presentations for their own use. The written guide will include chapters on how to edit a presentation script to describe local services and concerns, how to devel-

op a slide program, how to deliver a scripted slide presentation, and how to evaluate the impact of the presentation on an audience.

6) Policy Training in State Disabilities Planning: State advisory committees on disabilities try to bridge the gap between disabled citizens and the executive agencies and legislative bodies designed to serve them. However, the committees often lack crucial information about disability issues, such as employment, and this limits their ability to respond effectively to disabled citizens' concerns.

This project will provide training and technical assistance to the Kansas Advisory Committee on Employment of the Handicapped (KACEH). The goal will be to develop and communicate a document, Policy Choices on Employment, that will become a prototype for providing technical assistance to all state planning committees on disabilities.

Once the document is completed, it will be made available to state advisory committees on disability, legislative bodies, and staff of vocational rehabilitation and other executive agencies. Portions of the document will be used to assist policymakers in making choices about various issues related to employment, such as job training and modifications in the work place. In addition, the Policy Choices on Employment document will serve as a model for other researchers interested in analyzing state policies related to employment and other disability issues.

7) Improving Media Portrayals of Persons With Disabilities: Media professionals are in an ideal position to shape the public image of people with disabilities. Their capacity to communicate ideas and present appropriate models is unequalled in our society. Yet, the media has been criticized for perpetuating stereotypes through inaccurate portrayals of disabled people.

Inaccurate portrayals may persist because there are no clear guidelines indicating a preferred style and no standard terminology for writing and reporting about disabilities. In response to recommendations from the RTC/IL Advisory Board and consumers nationwide, the RTC/IL staff developed a pamphlet, "Guide-

lines for Reporting and Writing About People With Disabilities." It was compiled with input from over 50 national disability organizations and represents a consensus on acceptable terminology and portrayals concerning disability issues. More than 30,000 copies have been disseminated to disability organizations and service agencies throughout the country.

The Guidelines were submitted to the boards of editors of the Associated Press and the United Press International for possible inclusion in upcoming editions of their stylebooks. This will help establish national policies on the use of disability terms and portrayals. But, in addition to national policies, consumer groups need strategies to influence portrayals by their own local media to help ensure adoption of established guidelines.

8) Evaluating the Impact of ILCs: Independent living service providers and policymakers need valid, reliable, and economical methods to evaluate the impact of ILCs. The goal of the program evaluation project, led by James Budde, is to develop and field test evaluation standards that can be used by ILCs. As a preliminary step, investigators have developed methods to measure attainment of consumer goals, ILC impact, and the removal of handicapping conditions within the community.

9) Social Support Systems for Enhancing Independent Living: Self-help and social support have been major components of the IL movement. For many disabled citizens, ILCs are their primary social support system. Research analyzing social support systems is limited and focuses primarily on either theoretical discussions about the importance of social support or descriptions of individual support programs. There is little research demonstrating the effectiveness of such groups in general, or their role in promoting independence of disabled persons in particular.

In the IL field, research is needed to determine: 1) the prevalence of social support systems for people with disabilities; 2) the relationship between social support groups and ILCs; 3) characteristics of successful support systems; and 4) procedures needed to enhance social support group effectiveness.

Future Plans—Training and Dissemination Activities: RTC/IL plans a number of training and dissemination activities in the areas of university training, in-service training and technical assistance, and product development and dissemination.

An IL leadership training program has been proposed wherein disabled persons will receive scholarships to pursue academic training and field-based practice. The program is intended to provide talented disabled persons with training and experience needed to assume leadership roles in the IL movement.

Product development and dissemination activities for next year include continued publication of the *Independent Living Forum*, development of one additional *RTC/IL Monograph*,

and development of numerous training manuals and resource directories for inclusion in the *RTC/IL Bibliography*. The *Forum* is published quarterly and disseminated to over 1,000 individuals and organizations. We expect to complete or initiate work on 10-12 training manuals and resource directories for the *Bibliography*. Additional research publications are planned for disseminating research outcomes in the rehabilitation field.

Over the next 5 years, RTC/IL will continue to explore new research areas and expand knowledge about the field. We will also continue to make sure consumers are satisfied with the direction of our research, the kind of training we provide, and the products we create.

Growth and Bone Haemodynamic Responses to Castration in Male Rats: Reversibility by Testosterone

A. Schoutens; M. Verhas; M. L'Hermite-Baleriaux; M. L'Hermite; A. Verschaeren; N. Dourov; M. Mone; A. Heilporn; A. Tricot

The Universities of Erasme and Brugmann, The Free University of Brussels, and the Center for Traumatology and Rehabilitation, 1020 Brussels, Belgium

Sponsor: None Listed

Final Results—Orchidectomy in postpubertal 55-day-old rats, compared to sham-operated controls, led beyond 2 months to a decrease in body weight (87 percent of controls by 120 days), tibial length (97 percent of controls), and in tibial calcium content (85 percent of controls). Bone plasma flow increased 3 times to reach a peak at 31 days; it was decreased, but not significantly, at 86 and 120 days. The number of osteoclasts was maximal at 51 days (x 2.3) and was still elevated at 120 days. The calcium ac-

cretion rate increased briefly at 31 days (110 percent of controls) and was diminished at 86 and 120 days (78 percent of controls).

The initial "physiological" changes in the tibia occurred before any weight change and might be directly due to the lack of androgens. They can be interpreted as inducing the conditions for enhanced bone resorption. Testosterone replacement therapy, initiated after the initial haemodynamic response, inhibited the negative effect of castration on bone growth.

Sponsoring Agencies and Organizations

American Corrective Therapy Association, Inc.

Rosedale, NY 11422

David Ser, Executive Director

In section IV. **Spinal Cord Injury, B. Medical Treatment:** Circulorespiratory Effects of Dynamic Arm Exercise in Spinal Cord Injured, Quadriplegic Males.

The American Paraplegia Society

New York, NY 10016

James J. Peters, Director

In section IV. **Spinal Cord Injury, B. Medical Treatment:** Prospective Randomized Clinical Trial of Thyrotropin-Releasing Hormone (TRH) as a Therapy for Spinal Cord Injury.

Apple Education Foundation

Cupertino, CA 95014

Fred Silverman, Acting Manager

In section IV. **Spinal Cord Injury, F. Environmental Control Systems for the Severely Disabled:** Voice Control for Disabled Children.

The Arthritis and Rheumatism Council of Scotland

London WC1, England

Sir Archibald Forbes, Director

In section III. **Total Joint Replacement and Other Orthopaedic Implants, D. Other:** Evaluation of Elbow Joint Function Post-Elbow Joint Arthroplasty.

Bioengineering Alliance of South Carolina

Clemson University, Clemson, SC 29634

R. Larry Dooley, Director

In section III. **Total Joint Replacement**

and Other Orthopaedic Implants, A. General: Expert Manufacturing System for Custom Prosthesis; Porous Polyethylene as a Reconstructive Material.

In section VI. **Biomechanics, C. Human Locomotion and Gait Training:** Effect of Shock-Absorbing Materials on Heel-Strike Forces.

Cerebral Palsy Research Foundation of Kansas

Wichita, KS 67208

Jon F. Jonas, Jr., President

In section VI. **Biomechanics, D. Upper Limb Applications:** Analysis of Hand Performance Patterns in Able-Bodied and Cerebral-Palsied Subjects.

Channel 10 Children's Medical Research Foundation of S.A.

Gilberton 5081, South Australia

In section IV. **Spinal Cord Injury, G. Wheelchairs, Including Seating and Controls:** Wheelchair Seating Effectiveness

In section XII. **Muscular Dystrophy:** A Random Crossover Trial of Respiratory Muscle Endurance Training in Duchenne Muscular Dystrophy.

Clayton Foundation for Research

Baylor College of Medicine, Houston, TX 77030

Herman A. Jenkins, M.D., Director

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 1. General:** Sensorimotor Aspects of Visual Rehabilitation Using Head-Mounted Magnification.

Columbia University College of Physicians

New York, NY 10037

Hendrick Ben Dixen, M.D., Dean

In section XVI. Miscellaneous: A Manual for the Development of a Program in Rehabilitation Medicine in a Ghetto Hospital.

Commonwealth Department of Community Services
Sidney, 2000 New South Wales, Australia

In section XVI. Miscellaneous: Supported Employment.

Commonwealth Department of Veterans' Affairs
Woden ACT 2606, Australia
D. Volker, Director

In section I. Amputations and Limb Prostheses, B. Lower Limb, 3. Above-Knee: Transparent Flexible Sockets for Above-Knee Prostheses.

In section I. Amputations and Limb Prostheses, C. Upper Limb, 2. Below-Elbow: Acceptability of the "Contour" Terminal Device for Below-Elbow Amputees.

Consejo Nacional de Investigaciones Cientificas y Técnicas
1033 Buenos Aires, Argentina
Carlos Abeledo, Director

In section II. Orthotics: Bioengineering Research and Development at Instituto de Mecánica Aplicada (IMA).

In section IV. Spinal Cord Injury, G. Wheelchairs, Including Seating and Controls: Bioengineering Research and Development at Instituto de Meca

Dallas Rehabilitation Foundation
University of Texas, Arlington, TX 76019
Raymond L. Dabney, Director

In section V. Functional Assessment: Improved Methods of Quantification of Function/Performance; Development of a Computer-Automated System for Functional Assessment; Clinical Evaluation and Application of a Computer-Automated System for Functional Assessment - Part 1; Clinical Evaluation and Application of a Computer-Automated System for Functional Assessment - Part 2.

Dallas Rehabilitation Institute
University of Texas, Arlington, TX 76019
Malcolm Berry, Executive Director

In section V. Functional Assessment: Improved Methods of Quantification of Function/Performance.

Danish Medical Research Fund
Gentofte Hospital, University of Copenhagen, DK-2900 Hellerup, Denmark

In section VI. Biomechanics, C. Human Locomotion and Gait Training: Gait Analysis by Use of an Instrumented Treadmill.

Department of Health and Social Security
London SE 1, England
Norman Fowler, Director

In section IV. Spinal Cord Injury, G. Wheelchairs, Including Seatings and Controls: Wheelchair Controls.

DePuy
Warsaw, IN 46580
James Lent, President

In section III. Total Joint Replacement and Other Orthopaedic Implants, C.. Knee: Synatomic Knee Clinical Investigation.

Dow Corning Company
Auburn, MI 48611
Lawrence Reed, President

In section VII. Wound and Fracture Healing: Management of Burn Injuries.

Easter Seal Research Foundation, National Easter Seal Society
Chicago, IL 60612
Rita McGaughey, Associate Director

In section IV. Spinal Cord Injury, E. Communication Methods and Systems for the Severely Disabled: PACA-Portable Anticipatory Communication Aid.

D.D. Eisenhower Army Medical Center
Fort Gordon, GA 30905
Colonel Lewis B. Harden, Director

In section I. **Amputations and Limb Prostheses, A. General:** Thermographic and Electromyographic Correlates of Stump and Phantom Limb Pain; Psychological Factors Influencing Chronic Phantom Limb Pain: Analysis of the Literature and a Survey of Locus of Control.

The Frances and Augustus Newman Foundation
Bristol, 8516 1QT, England
and

Head Injury Recovery Trust (H.I.R.T.)
Bristol, 8516 1QT, England

In section XIV. **Head Trauma and Stroke:** An Evaluation of a Microcomputer-Based Cognitive Rehabilitation Program for the Severely Head-Injured.

Hafnia Insurance, Ltd.
Holmens Kanal 9, Copenhagen, Denmark

In section VI. **Biomechanics, C. Human Locomotion and Gait Training:** Gait Analysis by Use of an Instrumented Treadmill.

Harlem Hospital Center
New York, NY 10037
Charles Windsor, Executive Director

In section XVI. **Miscellaneous:** A Manual for the Development of a Program in Rehabilitation Medicine in a Ghetto Hospital.

Health Systems Research and Development, Veterans Administration
810 Vermont Avenue, NW, Washington, DC 20420
Perkash L. Grover, Ph.D., Acting Chief

In section XV. **Geriatrics:** Nutrition and Health in the Aging Veteran Population; Evaluation of Independent Living Services for the Chronically Ill Elderly; and A Geriatric Record and Multidisciplinary Planning System.

Helen Keller National Center
Mississippi State University, Mississippi State, MS 39763
William Graves, Ph.D. Director

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 1. General:** Factors Influencing Employment Outcomes of Legally Blind Rehabilitation Clients Who Have Hearing Impairments; Prevocational Skill Acquisition of Multiply Handicapped Blind Youth Using Adapted Electromechanical Assessment Devices.

Human Services Research Institute
Cambridge, MA 02140
Valerie Bradley, Director

In section XVI. **Miscellaneous:** HSRI Mental Health Strategic Planning and Resource Allocation Model.

Institute for Orthopedic Technics Research
A-1050 Vienna, Austria
Dr. Herbert Kristen, Director

In section I. **Amputations and Limb Prostheses, C. Upper Limb, 2. Below-Elbow:** The VIENNA ROTATION ARM: A Below-Elbow Prosthesis.

Institute for Research in Behavioral Neuroscience
New York University Medical Center, New York, NY 10016
Jason Brown, MD., Director

In section XIV. **Head Trauma and Stroke:** A Prosthesis for Writing in Aphasia.

Institute of Physical and Chemical Research
Office for Life Science Promotion, Agency of Science and Technology of the Japanese Government, Tokyo 162, Japan
Yasuhisa Sakurai, Director

In section II. **Orthotics:** Development of a Powered Orthosis for Lower Limbs.

Japanese Ministry of Education

3-2-2 Kasumigaseki, Chiyoda-ku, Tokyo, 100
Japan

Masajuro Shiokawa, Director

In section XIII. Sensory Aids, B. Deafness and Hearing Impairment: A Microprocessor and Signal Processor-Based Speech Training System for the Hearing Impaired.

Kenny Michigan Rehabilitation Foundation

Southfield, MI 48075

Franklin C. Hazard, Executive Director

In section XIV. Head Trauma and Stroke: The Microcomputer as a Cognition Orthosis; COGORTH: Cognition Orthosis Programming Language.

Langer Biomechanics, Inc.

Hines, IL 60141

In section III. Total Joint Replacement and Other Orthopaedic Implants, A. General: Weight Distribution in the Foot Before and After Surgical and Orthotic Intervention for Hallux Sigidus.

Liberty Mutual Insurance Company

Boston, MA 02215

N. Gary Countryman, President

In section IV. Spinal Cord Injury, E. Communication Methods and Systems for the Severely Disabled: Neuromuscular Assessment for Assistive Communication Device.

In section VI. Biomechanics, B. Spine: Trunk Analysis System.

In section VI. Biomechanics, E. Other: A Model for Postural Sway. Visual Control of Step Length During Running.

In section VIII. Properties of Muscle, A. General: Measurements of Postural Sway; Cross-Talk Between Myoelectric Signals of Adjacent Muscles; Topical Anesthesia and Muscle Hypertonicity; Surface Electrode Design; Multi-Channel Surface Electrode Array.

In section VIII. Properties of Muscle, B. Muscle Contraction: The Myoelectric Signal Decomposition Technique; Control of

Antagonist Muscles; Motor Control in Movement Disorders; Synchronization of Motor Unit Discharges; Force Output of Muscles During Voluntary Isometric Contraction; Sensorimotor Interaction in Motor Unit Control.

In section VIII. Properties of Muscle, C. Muscle Fatigue: Muscle Fatigue and the Myoelectric Signal; Fatigue Properties of Motor Units During Voluntary and Electrically Induced Contractions; Muscle Fatigue Monitor.

Louisiana State University Bioengineering Foundation

Louisiana State University Medical Center,
New Orleans, LA 70112

Perry G. Rigby, M.D., Chancellor

In section VI. Biomechanics, A. Joint Studies, 1. General: The Antagonist Muscle and Its Role in Maintaining Joint Stability.

In section VI. Biomechanics, A. Joint Studies, 2. Lower Limb: Development of Diagnostic and Therapeutic Procedure for Anterior-Cruciate-Ligament-Deficient Knees.

In section VIII. Properties of Muscle, B. Muscle Contraction: The EMG-Force Relationships of Skeletal Muscles Depends on Their Firing Rate and Recruitment Control Strategies.

March of Dimes Birth Defects Foundation

1275 Mamaroneck Avenue, White Plains, NY
10605

Charles L. Massey, President

In section XIII. Sensory Aids, A. Blindness and Low Vision, 1. General: Sensory Aids and Spatial Training of Blind Children.

Massachusetts Institute of Technology, Undergraduate Research Opportunities Program

Cambridge, MA 02139

Norma McGavern, Ph.D., Director

In section XIII. Sensory Aids, C. Speech Impairment: Prescription Guide for Nonvocal Communication Devices.

Mississippi State University
 Rehabilitation Research and Training Center
 on Blindness and Low Vision, Mississippi State,
 MS 39762
William Graves, Ph.D., Director

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 1. General:** The Elderly Blind Client; Factors Associated with Employment Outcome; Factors Influencing Employment Outcomes of Legally Blind Rehabilitation Clients Who Have Hearing Impairments; Prevocational Skill Acquisition of Multiply Handicapped Blind Youth Using Adapted Electromechanical Assessment Devices; Low Vision Performance as a Function of Environmental and Stimulus Characteristics; Electromechanical Vocational Assessment Technology for the Evaluation of Industrial Work Abilities of Blind; Modification and Adaptation of the Vocational Education Readiness Test for Blind/Severely Visually Impaired Individuals; Development and Validation of a Work Environment Visual Demands (WEVD) Protocol; The Effects of Sensory Aids on the Employability and Career Development of Visually Impaired Persons; Perception of Teachers, Rehabilitation Counselors, and Rehabilitation Administrators of the Career Development Needs of Blind and Visually Impaired Students and Adults; Career Development Needs of Blind and Visually Impaired Students and Adults; Predicting Work Status Outcomes of Blind/Severely Visually Impaired Clients of Rehabilitation Agencies; Blind Clients Closed as Homemakers: Employment Outcome Antecedents; Training Opportunities Profile for Visually Impaired Persons: (TOP-VIP); The Unsuccessfully Closed Blind Client: Employment Outcome Antecedents.

National Eye Institute
 Bethesda, MD 20892
Carl Kupfer, Ph.D., Director

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 1. General:** Microcomputer Magnification for Low-Vision Users; Sensorimotor Aspects of Visual Rehabilitation Using Head-Mounted Magnification; Trisensor Rearing with Infant Macaques;

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 3. Reading Aids;** Tactile Paper for Visually Handicapped.

National Institute on Disability and Rehabilitation Research (NIDRR)

[Formerly the National Institute of Handicapped Research (NIHR). Since the title of NIDRR changed during the preparation of this publication, the original title has been used throughout.]

National Institute of Handicapped Research, Department of Education (NIHR)
 Washington, D.C., 20202-2305
David B. Gray, Acting Director

In section I. **Amputations and Limb Prostheses, A. General:** Development of Materials for Percutaneous Passage.

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 3. Above-Knee:** A Rigid Knee Prosthesis; A Telemetric Data Acquisition and Processing System for Biofeedback Training and as a Diagnostic for Human Movement Training.

In section I. **Amputations and Limb Prostheses, C. Upper Limb, 1. General;** Improvement of Body-Powered Upper-Limb Prostheses; Myoelectric Prosthetic System; Extended-Limb Prostheses; An Electric Artificial Limb for Children Without Limbs; Quantification for the Functional Capability of Upper Extremity Amputees.

In section III. **Total Joint Replacement and Other Orthopaedic Implants, A. General:** The Effect of Notching of Simplex-P Bone Cement on the Fatigue Lives of Regular Versus Vacuum-Mixed Specimens; Bone Remodeling Around Ingrowth Joint Implants; Investigation of the Bone/Bone Cement/Implant Interface Formed by Total Joint Replacement; Mechanical Properties of Trabecular Bone Tissue; Development of Biologic Cement for Fixation of Skeletal Implants.

In section III. **Total Joint Replacement and Other Orthopaedic Implants, C.. Knee:** Stiffness and Porosity of Cancellous Bone from Total Knee Patients.

In section IV. **Spinal Cord Injury, A. General:** Retrospective Analysis of the National Spinal Cord Injury Care System Database; Documenting and Utilizing Programs Which Provide Community Adjustment and Independent Living Services for Persons with SCI; Assessment, Development and Clinical

Applications of Strategies to Coordinate Services for SCI Clients after Discharge; Longitudinal Assessment of Physical Therapy Factors in the Rehabilitation Process that Affect the Quality of Life of Persons with SCI; Longitudinal Assessment of the Utilization of Upper Extremity Assistive Devices Prescribed for the Spinal Cord Injured Quadriplegic; Outcome Studies Pertinent to the National Model Spinal Cord Injury System; Development of Reconditioning Exercise Program for Patients with Paraplegia; Vocational Evaluation for Quadriplegics with a High School Education or Less; A Center for Acute Spinal Cord Injury: Epidemiology and Economic Costs of Spinal Cord Trauma.

In section IV. **Spinal Cord Injury, B. Medical Treatment:** Effect of Intermittent Catheterization in Renal Stone Formation in Spinal Cord Injury Patients; Natural History and Clinical Course of Urinary Tract Complications in Patients with Spinal Cord Dysfunction; A Bladder Sensor for Urinary Incontinence; Incidence, Characteristics and Clinical Significance of Anemia in Patients with Spinal Cord Dysfunction; Effects of Nutritional Intervention During the Acute Phase of Spinal Cord Injury; Incidence and Clinical Significance of Impaired Brain Function in Spinal Cord Injury; Pain Secondary to Gunshot Wound During the Initial Rehabilitation Process in Spinal Cord Injury Patients; Didronel in the Prevention of Heterotopic Ossification Following SCI: Determination of an Optimal Treatment Schedule; The Relationship of Nutritional Status and the Occurrence of Secondary Complication in Spinal Cord Injury Patients; Collagen Dysfunction in Quadriplegia; Effects of Spinal Cord Injury on Drug Metabolism; Collagen Dysfunction in Quadriplegia (Co-sponsor: Paralyzed Veterans of America).

In section IV. **Spinal Cord Injury, D. Independent Living for the Severely Disabled:** Parameters of Independent Living Programs: A Longitudinal Study; Independent Living in Rural Areas: A Longitudinal Study; An Operational Definition of Independence.

In section IV. **Spinal Cord Injury, E. Communication Methods and Systems for the Severely Disabled:** Software Development of Alternate Inputs to IBM PC; PACA-Portable Anticipatory Communication Aid; Development of a Unified Quantitative Model for Augmentative Communication Systems.

In section IV. **Spinal Cord Injury, G. Wheelchairs, Including Seating and Controls:**

University of Virginia Rehabilitation Engineering Center.

In section IV. **Spinal Cord Injury, I. Functional Electrical Stimulation, 2. Upper Limb Applications:** Recruitment Properties of Nerve Cuff and Epimysial Electrodes; Ljubljana Rehabilitation Engineering Center; Implantable Multichannel Implant Systems.

In section V. **Functional Assessment:** Predictive Assessment in Prescription of Functional Aids for the Motor Disabled; Development of a Computer-Automated System for Functional Assessment (Cosponsors: University of Texas at Arlington; Dallas Rehabilitation Foundation; University of Texas Health Science Center at Dallas); Clinical Evaluation and Application of a Computer-Automated System for Functional Assessment - Part 1; Clinical Evaluation and Application of a Computer-Automated System for Functional Assessment - Part 2; Quantification of Mobility Performance for Functional Assessment, Diagnosis, and Therapy of Neuromuscular, Skeletal, and Synovial Joint Dysfunctions; Upper Extremity Control Utilizing Functional Neuromuscular Stimulation.

In section VI. **Biomechanics, C. Human Locomotion and Gait Training:** Swing-Through Crutch Ambulation by Persons with Paraplegia.

In section VI. **Biomechanics, C. Human Locomotion and Gait Training:** Gait, Balance and Symmetry in Hemiplegia: An Analysis With and Without Biofeedback.

In section VII. **Wound and Fracture Healing:** Enhancement of Ulcerated Tissue Healing by Electrical Stimulation.

In section X. **Arthritis:** Arthritis Rehabilitation Unit; Impact of Arthritis Self-Care for Rural Persons.

In section XI. **Low Back Pain:** Low Back Pain Assessment, Prevention, and Rehabilitation.

In section XIII. **Sensory Aids A. Blindness and Low Vision, 1. General:** Computer Access Aids for the Blind: An Auditory Data-Flow Indicator; Auditory Breakout Box; Pediatric Vision Screening.

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 1. General:** The Elderly Blind Client: Factors Associated with Employment Outcome; Factors Influencing Employment Outcomes of Legally Blind Rehabilitation Clients Who Have Hearing Impairments; Prevocational Skill Acquisition of Multiply Handicapped Blind Youth Using Adapted Electromechanical Assessment Devices; Low

Vision Performance as a Function of Environmental and Stimulus Characteristics; Electromechanical Vocational Assessment Technology for the Evaluation of Industrial Work Abilities of Blind; Modification and Adaptation of the Vocational Education Readiness Test for Blind/Severely Visually Impaired Individuals (VERT); Development and Validation of a Work Environment Visual Demands (WEVD) Protocol; The Effects of Sensory Aids on the Employability and Career Development of Visually Impaired Persons; Perception of Teachers, Rehabilitation Counselors, and Rehabilitation Administrators of the Career Development Needs of Blind and Visually Impaired Students and Adults; Career Development Needs of Blind and Visually Impaired Students and Adults; Predicting Work Status Outcomes of Blind/Severely Visually Impaired Clients of Rehabilitation Agencies; Blind Clients Closed as Homemakers: Employment Outcome Antecedents; Training Opportunities Profile for Visually Impaired Persons: (TOP-VIP); The Unsuccessfully Closed Blind Client: Employment Outcome Antecedents.

In section XIII. Sensory Aids A. Blindness and Low Vision, 3. Reading Aids: Enhancing the Reading Skills of Low Vision Individuals with Macular Loss.

In section XIII. Sensory Aids, B. Deafness and Hearing Impairment: Robotic Finger-Spelling Hand.

In section XIII. Sensory Aids, C. Speech Impairment: Prescription Guide for Nonvocal Communication Devices

In section XVI. Miscellaneous: Family Factors and Work Adjustment of Handicapped Mexican-Americans; The Research and Training Center on Independent Living (RTC/IL).

National Institute of Neurological and Communicative Disorders and Stroke
National Institutes of Health, HEW Building,
Bethesda, MD 20205
Murray Goldstein, D.O., M.P.H., Director

In section XIII. Sensory Aids, C. Speech Impairment: Prescription Guide for Nonvocal Communication Devices.

In section XIV. Head Trauma and Stroke: Computer Acceptance of Maladaptive and

Adaptive Aphasic Behaviors; Device Evaluation for Cognitively and Motor-Impaired People.

In section XVI. Miscellaneous: The Definition of "Peer": Consumer Perspectives and Significance in the Delivery of Counseling Services.

In section XVI. Miscellaneous: Evaluation of Rehabilitation Technology; Information Resources; Social Skills Training for Older and Younger Persons with Severe Physical Disabilities.

National Institutes of Health
Bethesda, MD 20892
James Wyngaarden, M.D., Director

In section I. Amputations and Limb Prostheses, A. General: Myoelectric Controller for Orthotic/Prosthetic Systems.

In section III. Total Joint Replacement and Other Orthopaedic Implants, A. General: Segmental Bone and Joint Replacement After Tumor Resection.

In section IV. Spinal Cord Injury, I. Functional Electrical Stimulation, 2. Upper Limb Applications: Implantable Systems for Stimulation of Skeletal Muscle.

In section VII. Wound and Fracture Healing: Acceleration of Fracture Healing Electrical Fields; Biomechanics of Metastatic Defects in Bone.

In section X. Arthritis: Multipurpose Arthritis Center: Stanford University; Multipurpose Arthritis Center: Boston University; Northeast Ohio Arthritis Center Support: Legal Aspects of Chronic Illness — A Study of Arthritis Patients; Multipurpose Arthritis Center: Community Component — Coping Responses to Rheumatoid Arthritis; Social Security Disability Study; Role Performance Limitations in Women with RA; Multipurpose Arthritis Center: Pain Management in Arthritis; Motor Skill Learning; Mini-Sabbatical for Physical and Occupational Therapists; Multipurpose Arthritis Center: Community Component — Studies Using a Panel of Rheumatoid Arthritis Patients; Secondary Data Studies; Education Component—Arthritis In-Service Program for Home Health Agencies; A National Arthritis Data Source (ARAMIS); Epidemiology Program Project: Rheumatoid Arthritis — Course and Outcome; Multipurpose Arthritis Center: Problem-Oriented Educational Program for

Arthritis Using Aerobic-Type Exercise; Multipurpose Arthritis Center: Education—Arthritis Patient Education Model; Medical Allied Health Professions Integrated Curriculum in Arthritis; Arthritis Rehabilitation Training Program for Industrial Managers; Disability Determination of Arthritis; Robert B. Brigham Multipurpose Arthritis Center: Feasibility Study: Evaluation of Total Knee Replacement by Gait Analysis; Community Component—Social Security Disability Study; Study of Behavioral Aspects of Rheumatoid Arthritis; Energy Conservation and Joint Protection in Rheumatoid Arthritis.

In section XI. **Low Back Pain: Chronic Pain Mechanisms and Manifestations: Psychological Treatment for Chronic Back Pain.**

In section XIII. **Sensory Aids A. Blindness and Low Vision, 3. Reading Aids: Tactile Paper for Visually Handicapped.**

In section XIII. **Sensory Aids B. Deafness and Hearing Impairment: Development of a Cochlear Prosthesis; Matching Speech to Residual Auditory Function; Hearing Aid Characteristic Selection; Rehabilitation Strategies for the Hearing Impaired: A Digitally Programmable Master Aid; High-Frequency Acoustics in the External Human Ear (Phase I); Multimicrophone Monaural Aids for the Hearing Impaired; Processor-Controlled Hearing Aid.**

In section XIV. **Head Trauma and Stroke: Establishment of a Central Nervous System Trauma Center: University of California/San Diego; Establishment of a Central Nervous System Trauma Center: Yeshiva University; Socio-Cultural Mechanisms of Rehabilitation in Old Age; Remediation of Left-Sided Neglect and Interpersonal Communication Following Hemispheric Strokes; Precursors of Stroke Incidence and Prognosis; Recovery from Aphasia in Stroke; Rehabilitative Software for Head Trauma Victims; Treatment of Affective Deficits in Stroke Rehabilitation.**

In section XV. **Geriatrics: Geriatric Dentistry Academic Award: Tufts University; Geriatric Medicine Academic Award: University of Chicago; Geriatric Medicine Academic Award: University of North Carolina/Chapel Hill; Geriatric Medicine Academic Award - NIA: New York Medical College; NIA Academic Award: University of**

North Carolina/Chapel Hill; Does Improvement in Mortality Mean Better Health?; Morbidity Risk Assessment in the Elderly; The Lives and Needs of Aging Mentally Retarded Persons; Effects of Aging Upon Communication: Prevalence of Hearing Loss; Perceptual Retention and Age; Learned Modification of Visceral Function in Man; Audiologic Findings in Aging Down's Syndrome Patients.

National Research Council of Canada

Ottawa, Ontario K1A 0R6 Canada

Dr. Larkin Kerwin, Director

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 1. General: Research into the Development of a Nonisomorphic Codification System for Electrocutaneous Sight Substitution.**

National Science Foundation

Washington, DC 20550

Erich Bloch, Director

In section V. **Functional Assessment: Quantification of Mobility Performance for Functional Assessment, Diagnosis, and Therapy of Neuromuscular, Skeletal, and Synovial Joint Dysfunctions.**

In section VI. **Biomechanics, A. Joint Studies, 2. Lower Limb: Comprehensive, Quantitative, Predictive Model of the Human Knee Joint.**

National Spinal Cord Injury Association

Newton, MA 02158

Jonathan Spack, J.D., Executive Director

In section IV. **Spinal Cord Injury, A. General: Corticospinal Systems; Role of Intrinsic Motoneuron Properties in Abnormal Rate Regulation After Spinal Injury; An Implantable Sensor for Two-Degree-of-Freedom Position Transduction; Trial of a 5-Lipoxygenase Inhibitor in Experimental Spinal Cord Injury.**

In section IV. **Spinal Cord Injury, B. Medical Treatment: A Collision Block Technique for Micturition Assist: Pre-Clinical**

Studies; Urinary Bladder Ganglion Reorganization Following Lesions.

In section IV. **Spinal Cord Injury, C. Spinal Cord Regeneration:** A Study of Phosphoprotein in a Regenerating CNS Tract; Spinal Cord Regeneration of Descending Locomotor Command Systems in a Lower Vertebrate, the Lamprey; Fetal Spinal Cord Transplantation into the Chronically Injured Rat Spinal Cord; Study to Determine if Localized Extracellular Proteolysis is a Requirement for Successful Regeneration of Nervous Tissue; Axon Regeneration in the Mammalian Spinal Cord in Response to Surgical Denervation and Nerve Growth Factor.

Natural Services and Engineering Research Council
Ottawa, Ontario K1A 1H5 Canada

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 1. General:** Research into the Development of a Nonisomorphic Codification System for Electrocutaneous Sight Substitution.

Netherlands Heart Foundation
Sophialaan 10, 2514 JR, Den Haag, The Netherlands
H. L. Guldemon, Director

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 1. General:** Relation Between Cardiac Condition of Leg Amputees and the Success of Their Prosthetic Rehabilitation

New York State Department of Health
Albany, NY 12236
David Axelrod, M.D., Director

In section IV. **Spinal Cord Injury, B. Medical Treatment:** Biochemical Analysis of Sweat as an Indicator of Tissue Viability; Remote Monitoring of Pressure Relief Activity and Sitting Asymmetry in the Wheelchair User.

In section IV. **Spinal Cord Injury, G. Wheelchairs, Including Seating and Controls:** CUSHFIT: An Expert System for Wheelchair Cushion Prescription.

In section VII. **Wound and Fracture Healing:** Stimulation of Repair of Cortical Bone Transplants by Implantation of Piezoelectric Materials: A Development Study.

Nippon Medical School
1-1-5 Sendagi, Bunkyo-ku, 113 Tokyo, Japan

In section VIII. **Properties of Muscle, B. Muscle Contraction:** Sensorimotor Interaction in Motor Unit Control.

Northern Ireland Department of Health
Donald House, Upper Newtownardes Road, Belfast, BT4 3SF, Northern Ireland
Richard Needham, Director

In section VI. **Biomechanics, C. Human Locomotion and Gait Training:** A Modular Gait Analysis System.

Northern Ireland Rehabilitation Engineering Centre
Musgrave Park Hospital, Belfast BT9 7JB, Northern Ireland

In section IV. **Spinal Cord Injury, G. Wheelchairs, Including Seating and Controls:** Seating Systems Analysis.

Office of Special Education and Rehabilitation Services
Washington, DC 20024

In section IV. **Spinal Cord Injury, E. Communication Methods and Systems for the Severely Disabled:** Application of Technology to Enhance the Employability of Severely Communicatively Impaired Individuals.

Orthopaedic Institute
Hospital for Joint Diseases, New York, NY 10003
Victor H. Frankel, M.D., Director

In section XI. **Low Back Pain:** Personality Characteristics and Their Effect on Post-

Surgical Adjustment; A Comparative Analysis of Electrical Stimulation and Exercise to Improve Trunk Strength and Endurance in the Adult Female.

Ortopedia GmbH/Kiel, West Germany
Salzredder 30, Postfach 6409, 2300 Kiel 14,
West Germany;
Eckhardt Hundhausen

and

Everest & Jennings/Camarillo, CA
Camarillo, CA 93010
Bradley C. Call, Director

In section IV. **Spinal Cord Injury, G.**
Wheelchairs, Including Seating and Controls:
Wheelchairs: On-Line Measurement and
Storage of the Load During a Field Trial.

Otto Bremer Foundation
St Paul, MN 55101
John Kostishack, Executive Director

In section XVI. **Miscellaneous: Rural**
Rehabilitation Technologies Database.

Outer Copenhagen Hospital
Administration
Gentofte Hospital, University of Copenhagen,
DK-2900 Hellerup, Denmark

In section VI. **Biomechanics, C. Human**
Locomotion and Gait Training: Gait Analysis
by Use of an Instrumented Treadmill.

Paralyzed Veterans of America, Spinal
Cord Research Foundation
Washington, D.C. 20006
Jack Powell, Executive Director

In section IV. **Spinal Cord Injury, A.**
General: Devices to Assist Transport, Diagnosis
and Treatment of Acute Spinal Injury Patients.

In section IV. **Spinal Cord Injury, B.**
Medical Treatment: Effects of Spinal Cord
Injury on Drug Metabolism

In section IV. **Spinal Cord Injury, A.**
General: Corticospinal Systems; An
Implantable Sensor for Two-Degree-of-Freedom

Position Transduction; Trial of a 5-
Lipoxygenase Inhibitor in Experimental Spinal
Cord Injury; Circulation and Metabolism in the
Decentralized Spinal Cord.

In section IV. **Spinal Cord Injury, B.**
Medical Treatment: A Collision Block
Technique for Micturition Assist: Pre-Clinical
Studies; A Laboratory Test to Predict and
Monitor Bone and Skin-Related Complications
in Spinal Cord Injured Patients; Skin
Temperature in Spinal Cord Injury Related to
Skin Breakdown; Prospective Randomized
Clinical Trail of Thyrotropin-Releasing
Hormone as a Therapy for Spinal Cord Injury;
Respiratory Dysfunction in Spinal Cord Injury:
Control of Ventilation; Urinary Bladder
Ganglion Reorganization Following Lesions;
Pharmacokinetics of Drugs in Spinal Cord
Injured Persons; Actions and Metabolism of
TRH in the Spinal Cord; Factors Affecting
Sodium and Water Homeostasis in SCI.

In section IV. **Spinal Cord Injury, B.**
Medical Treatment: Collagen Dysfunction in
Quadriplegia (Co-sponsor: National Institute of
Handicapped Research)

In section IV. **Spinal Cord Injury, C.**
Spinal Cord Regeneration: An *In Vivo* Model
to Assess the Neurotrophic Function of
Mammalian CNS Glia; Plasticity in the Injured
and Aging Mammalian Spinal Cord; A Study of
Phosphoprotein in a Regenerating CNS Tract;
Spinal Cord Regeneration of Descending
Locomotor Command Systems in a Lower
Vertebrate, the Lamprey; Fetal Spinal Cord
Transplantation into the Chronically Injured
Rat Spinal Cord; Study to Determine if
Localized Extracellular Proteolysis is a
Requirement for Successful Regeneration of
Nervous Tissue; Axon Regeneration in the
Mammalian Spinal Cord in Response to
Surgical Denervation and Nerve Growth
Factor; Axonal Regeneration in the Adult
Spinal Cords; Recovery of Function and
Anatomical Repair after Spinal Cord
Transections in Newborn and Adult Rats
Development and Regeneration of Afferent
Motoneuron Contacts in Rat Embryos;
Evaluation of a Novel Spinal Cord Injury
Model.

Polytecnico di Torino
Center for Study, 24C. Duca Abruzzi, Torino,
Italy
Lelio Stragiotti, Director

In section VIII. **Properties of Muscle, C.**

Muscle Fatigue: Fatigue Properties of Motor Units During Voluntary and Electrically Induced Contractions.

The Queen's University

Department of Mechanical Engineering,
Belfast, BT7 1NN, Northern Ireland

In section III. **Total Joint Replacement and Other Orthopaedic Implants, B. Hip:** Photoelastic Investigation of Hip Replacements.

Regency Park Centre for Young Disabled
Kilkenny, S.A., 5009, Australia

In section II. **Orthotics:** Lightweight Knee Joint for Child-Size Orthoses.

In section IV. **Spinal Cord Injury, G. Wheelchairs, Including Seating and Controls:** Powered Wheelchair Performance.

In section XII. **Muscular Dystrophy:** A Study of the Mechanism of Spinal Collapse in Duchenne Muscular Dystrophy; The Role of Spinal and Abdominal Muscles as Etiological Factors in Scoliosis in Neuromuscular Disorders.

Royal Institute of Technology

Stockholm S-100 44, Sweden
Gunnar Brodin, Director

In section XIII. **Sensory Aids, B. Deafness and Hearing Impairment:** An Experienced User of Tactile Information as a Supplement to Lip-Reading: An Evaluative Study; The Effects of Cochlear Implantation on Speech Production: A Case Study; A Single-Transducer Vibrotactile Aid to Lipreading.

Royal National Institute for the Blind

London W1, England
E. T. Boulter, Director

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 3. Reading Aids:** Facilitating the Use of Tape Recorded Text by Students with a Visual Handicap.

In section XIII. **Sensory Aids, C. Speech Impairment:** A Study of Speech Intelligibility Over a Public Address System.

Royal Ottawa Hospital

Regional Rehabilitation Centre, Ottawa,
Ontario K1H 8M2 Canada

Michael D. O'Riain, Ph.D., Director of
Rehabilitation Engineering

In section I. **Amputations and Limb Prostheses, C. Upper Limb, 1. General:** A Microprocessor-Controlled Prosthesis with Extended Physiological Proprioception.

In section IV. **Spinal Cord Injury, F. Environmental Control Systems for the Severely Disabled:** Machine Vision.

In section IV. **Spinal Cord Injury, G. Wheelchairs, Including Seating and Controls:** A New Wheelchair Bumper; Bicycle-Type Brakes for Wheelchairs.

Scottish Home and Health Department

Dover House, White Hall, London SW1,
England

W. K. Reid, Director

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 1. General:** Study of Alignment in Lower Limb Prostheses; Survey of Design Criteria for Prosthetic Knee and Ankle Joints.

In section II. **Orthotics:** Biomechanics of Knee Ankle Foot Orthoses.

In section V. **Functional Assessment:** Development and Evaluation of Pedobarograph (PBG) System for Clinical Use.

In section XVI. **Miscellaneous:** Laser Removal of Tattoos and Port Wine Stains.

Slovene Research Community

c/o University of Edvarda Kardelja, Prg.
Osvobodite 11, 61000 Ljubljana, Yugoslavia

In section VII. **Wound and Fracture Healing:** Enhancement of Ulcerated Tissue Healing by Electrical Stimulation.

Smith-Kettlewell Institute of Visual Sciences, Medical Research Institute

San Francisco, CA 94115

Arthur Jampolsky, M.D., Director

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 1. General:** Computer Access

Aids for the Blind: An Auditory Data-Flow Indicator; Auditory Breakout Box Pediatric Vision Screening.

Southern Australia Department of Transport and Design Arts Board of the Australian Council
Adelaide, 5000 South Australia

In section IV. **Spinal Cord Injury, G. Wheelchairs, Including Seating and Controls: Developing Safety Standards for Wheelchair Occupants in Vehicles.**

**Spinal Cord Research Foundation/
Vaughan Chapter**
Hines, IL 60141
Paul Kolb, President

In section IV. **Spinal Cord Injury, C. Spinal Cord Regeneration: Spinal Cord Explants Cultured on Carbon Filaments and Stimulated with Direct Current; Influence of Continuous Electrical Stimulation on the Spinal Cord Motor Neurons.**

State University of New York
Albany, NY 12222

In section X. **Arthritis: The Use of Biofeedback and Cognitive Behavioral Psychotherapy in the Treatment of Severe Rheumatoid Arthritis Patients: A Controlled Evaluation.**

TRIUMF, National Research Council of Canada Health and Welfare
Montreal Road, Ottawa, Ontario, K1A 0R6, Canada
Dr. Larkin Kerwin, Director

In section IV. **Spinal Cord Injury, F. Environmental Control Systems for the Severely Disabled: Development of a Robotic Arm for Use by the Physically Disabled.**

U.S. Army Clinical Investigation
D. D. Eisenhower Army Medical Center, Fort Gordon, GA 30905
Colonel Lewis B. Harden, Director

In section IV. **Spinal Cord Injury, B. Medical Treatment: Differences Between Chest Heat Patterns Shown by Complete and Incomplete Spinal Cord Injured Veterans.**

U.S. Social Security Administration
Baltimore, MD 21235
Martha McSteen, Commissioner

In section V. **Functional Assessment: Psychiatric Symptoms and the Functional Capacity to Work.**

United Cerebral Palsy of New Orleans
New Orleans, LA 70123 70112
Dominic MacCormack, Director

In section II. **Orthotics: A Viscoelastic Knee Brace for ACL Deficient Patients.**

University of Antwerp
Universiteitsplein 1, B2610 Wilrijk, Belgium

and

University of Louvain
Place de L'Universite 1, B1348, Ottignies-Louvain-la-Neuve, Belgium (In Collaboration with Forelec N.V. [Wilrijk])

In section XIII. **Sensory Aids, B. Deafness and Hearing Impairment: The Laura Cochlear Implant.**

University of Belgrade
Studentski Prg 1, 11000 Beograd, Yugoslavia

In section II. **Orthotics: Technical and Clinical Evaluation of Self-Fitting Modular Orthoses (SFMOs).**

Sponsoring Agencies and Organizations

University of Illinois

Division of Rehabilitation-Education Services,
Champaign-Urbana, IL 61801
Shirley McCluer, Ph.D., Director

In section IV. **Spinal Cord Injury, B. Medical Treatment:** Circulorespiratory Effects of Dynamic Arm Exercise in Spinal Cord Injured, Quadriplegic Males.

University of Michigan

Rehabilitation Engineering Division,
Department of Physical Medicine and
Rehabilitation, Ann Arbor, MI 48109
Simon P. Levine, Ph.D., Director

In section I. **Amputations and Limb Prostheses, C. Upper Limb, 1. General:** Prosthetic Terminal Device for Playing the Piano.

In section IV. **Spinal Cord Injury, E. Communication Methods and Systems for the Severely Disabled:** Electrically Controlled Talking Tracheostomy System; A Single Switch Keyboard Emulator for the IBM-PC.

In section IV. **Spinal Cord Injury, G. Wheelchairs, Including Seating and Controls:** A Computer Interface for the TIPE Seating Pressure Evaluator.

University of Strathclyde, Bioengineering Unit, Wolfson Centre

Glasgow G3 ONW, Scotland
J.P. Paul, Head of Department

In section III. **Total Joint Replacement and Other Orthopaedic Implants, B. Hip:** A New Method of Hip Function Assessment.

In section V. **Functional Assessment:** Long-term Ambulatory Physiological Surveillance Equipment (LAPSE).

University of Texas at Dallas

Health Science Center, Dallas, TX 76235

In section V. **Functional Assessment:** Improved Methods of Quantification of Function/Performance.

In section XI. **Low Back Pain:** Myoelectrical Assessment of Human Lumbar Muscle Function.

University of Texas at San Antonio

Health Science Center, San Antonio, TX 78284

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 1. General:** CAD/CAM of Lower Extremity Prostheses: The San Antonio System; Ultrasound as an Aid to Prosthetic Socket Design; Computerized Tomography as an Aid to Prosthetic Socket Design; The 3-D Digitizer as an Aid to Prosthetic Socket Design.

University of Utah

School of Medicine, Salt Lake City, UT 84132

In section III. **Total Joint Replacement and Other Orthopaedic Implants, B. Hip:** Skeletal Aging and Disease in Failure of Hip Surface Replacement.

Utah Foundation

Salt Lake City, UT 84101

In section XII. **Muscular Dystrophy:** A Random Crossover Trial of Respiratory Muscle Endurance Training in Duchenne Muscular Dystrophy.

Volunteers for Medical Engineering, Inc.

Lutherville, MD 21093

In section II. **Orthotics:** Standing Frame Lift Mechanism.

In section IV. **Spinal Cord Injury, E. Communication Methods and Systems for the Severely Disabled:** CompuTalk; Comm-Aid.

In section IV., **F. Environmental Control Systems for the Severely Disabled:** Voice-Actuated Control System; Blinkwriter; VME—CAD; and Overhead Rail Adaptation.

In section IV., **G. Wheelchairs, Including Seating and Controls:** Three-Wheeled Vehicle; Steiner Tractor Modification.

In section XIV. **Head Trauma and Stroke:** Aphasia Rehabilitation Program; Microwave Hyperthermia.

Walter Scott and Lyons Foundations

Newton, CT 06470

Thorpe Nickerson, Director

In section IV. **Spinal Cord Injury, G. Wheelchairs, Including Seating and Controls: Remote Monitoring of Pressure Relief Activity and Sitting Asymmetry in the Wheelchair User; CUSHFIT: An Expert System for Wheelchair Cushion Prescription.**

Wichita Rehabilitation Engineering Center
Wichita, KS 67208
John F. Jones, Jr.; John H. Leslie, Jr.; and Roy H. Norris, Co-Directors

In section IV. **Spinal Cord Injury, F. Environmental Control Systems for the Severely Disabled: Investigation of the Utilization of a Robotic Arm by Disabled Persons in the Workplace.**

**VETERANS ADMINISTRATION
REHABILITATION RESEARCH AND
DEVELOPMENT SERVICE**
810 Vermont Avenue, N.W.,
Washington, D.C. 20420
Margaret J. Giannini, M.D., Director

The mission of the Rehabilitation Research and Development program is to improve the quality of life for impaired, disabled, and handicapped veterans by making them more functionally independent. This mission has been significantly advanced as a result of ongoing research projects in such priority areas as prosthetics/amputation, spinal cord injury, and sensory aids.

In the areas of prosthetics, amputation, and orthotics, researchers are using new materials and computer technology to develop a new generation of artificial limbs—lighter, better fitting, and more comfortable limbs that permit more natural movement and more vigorous activities, including running, skiing, and swimming. For spinal cord injuries, the use of robotics is being studied, as is the possibility that computer-controlled electrical stimulation can be used to restore function to paralyzed limbs. Research projects in the area of sensory aids include the development of advanced mobility aids for the visually impaired, computer-based hearing aids, and a multi-hospital study in which remote, machine-assisted therapy is provided to stroke patients who are aphasic.

During FY 1986, 160 Rehabilitation R&D projects were being conducted at over 50 VA medical centers including the two Rehabilitation Research and Development Centers, the Rehabilitation R&D Evaluation Unit, and the Office of Technology Transfer. Ten interagency agreements were in effect for Rehabilitation R&D projects.

Hines Rehabilitation Research and Development Center
Edward Hines, Jr., Hospital, Hines, IL 60141
John Trimble, Ph.D., Director

Progress during 1986 in the Biomechanics Laboratory included study of the effects of low back pain treatment modalities, and weight distribution in the foot after surgical and orthotic interventions. The Human Factors Laboratory continued its focus on aids for individuals with visual impairment and included studies of mobility measurement, effects of preview distance on blind mobility, and predictions on the visual abilities of partially sighted persons. The Spinal Cord Injury Research Laboratories focused on spinal regeneration, electrical stimulation, and neural mechanisms underlying bladder dysfunction.

The following projects are reported in this issue:

In section III. **Total Joint Replacement and Other Orthopaedic Implants, A. General: Weight Distribution in the Foot Before and After Surgical and Orthotic Intervention for Hallux Rigidus.**

In section IV. **Spinal Cord Injury, B. Medical Treatment: Neural Mechanisms Underlying Bladder Dysfunction after Spinal Trauma.**

In section XI. **Low Back Pain: Effects of Low Back Pain Treatment Modalities on Lumbar Facet Loading.**

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 1. General: The Effects of Preview Distance on Blind Mobility; The Effectiveness of a Blind Rehabilitation Program; and Predicting the Visual Abilities of Partially Sighted Persons.**

In section XIII. **A. Blindness and Low Vision, 2. Mobility Aids: Measuring the Mobility of Blind Travelers.**

In section XV. **Geriatrics: Low Vision Rehabilitation and Age Related Maculopathy Syndrome.**

Rehabilitation Research and Development Center

Palo Alto Veterans Administration Medical Center, Palo Alto, California 94304
Larry Leifer, Ph.D., Director

The Center continued to focus on the development of new rehabilitation devices and techniques. The Orthopaedic Biomechanics program focused on the physiological and mechanical properties of bones. The advances in this area provided progress towards development of a framework for implant design. The Neural and Muscular Systems program used advanced technologies to study the interaction of human nerves, muscles, and bones. These studies included exploration of new methods for rejoining severed nerves, for electrically stimulating paralyzed muscles, and for measuring the number and size of physiologically active nerve fibers. The Human Machine Integration program used modern technology to develop devices to reduce the handicaps that are often associated with disability.

In 1986, the Center's special emphasis on the use of computers in rehabilitation research and development continued. Activities focused on computer simulations to provide new insights into the mechanisms of the human body, computer-aided design to speed the conceptualization and development of new products, and the incorporation of computer chips in the design of rehabilitation aids.

The following projects are reported in this issue:

In section III. **Total Joint Replacement and Other Orthopaedic Implants, A. General:** Bone Remodelling Around Porous-Ingrowth Implant; Design Analysis of Porous-Ingrowth Hip Replacement.

In section III, **C. Knee:** Design Concepts for a Porous-Ingrowth, Prosthetic Tibial Component.

In section III. **D. Other:** Stress Analysis for the Normal and Prosthetic Shoulder; Design of a Two-Component Finger Prosthesis

In section IV. **Spinal Cord Injury, A. General:** Devices to Assist Transport, Diagnosis and Treatment of Acute Spinal Injury Patients.

In section IV., **B. Medical Treatment:** Evaluation and Rehabilitation of Reproductive Function in Paraplegia; Skin Deformation and Blood Flow Under External Loading.

In section IV., **F. Environmental Control Systems for the Severely Disabled:** UHCI:

Ultrasonic Head Control Interface; Interactive Motion and Graphic Environmental Stimulation; Development and Evaluation of an Advanced Manipulation Aid for the Severely Disabled; Design of a Six-Axis Joystick for a Robotic Manipulation Aid; Design of an Omnidirectional Mobile Robot as a Manipulation Aid for the Severely Disabled; Computer Configuration of the Advanced Robotic Aid; Force-Proximity Integrated Sensory Perception for the Robotic Aid System; Architecture of the User Interface Software of the Robot Control Workstation; Design and Development of an Interactive Workstation for a Robotic Manipulation; Safety Features Implemented on a Puma 560 Robot Used in an Applications Setting; Laboratory Robotic Arm Testing Environment; Development of a Training and Reference Manual for a Robotic Manipulation Aid; Evaluation of Robotic Aids for the Severely Physically Disabled; Eating and Hygiene Tasks for the Robotic Aid; The Role of Choreographic Exploration in the Design of the Robotic Aid; Aesthetic Implications of Robotic Movement: A Case Study.

In section IV., **G. Wheelchairs, Including Seating and Controls:** Optimal Biomechanical Design/Development of Arm-Powered Mobility Devices; Seating Systems for Body Support and Prevention of Tissue Trauma.

In section V. **Functional Assessment:** Nerve-Bundle Conduction Velocity Distributions: Clinical and Research Applications.

In section VI. **Biomechanics, A. Joint Studies, 2. Lower Limb:** Computer Simulation of Knee Joint Mechanics.

In section VI., **C. Human Locomotion and Gait Training:** The Muscular Biomechanics of Human Posture; Human Movement Monitoring System to Study Posture, Walking and Jumping.

In section VI., **E. Other:** Mathematical Models for Bone Inelasticity and Bone Damage; Bone Fatigue and Creep Damage; Mechanical Stress Influences on Cartilage Degeneration and Ossification; The Influence of Exercise on the Regulation of Bone Density; Prediction of Cancellous Bone Apparent Density and Orientation; Development of a Musculoskeletal Model of the Human Lower Extremity; A Musculotendon Actuator for Use in Computer Studies of Neural Control and Biomechanics of Movement; Neuromuscular Control and Biomechanics of Pedaling and Jumping; Intermuscular Coordination of Mammalian

Movement; and The "White Knuckle" Technique for Studying Skin Behavior Under Load.

In section VII. **Wound and Fracture Healing:** Development of a Mathematical Model of Fracture Healing in Long Bones; Stress Analysis of Internal Fracture Fixation of Long Bones; Quantitative Evaluation of Nerve Repair; Nerve Coupler—Sutureless Peripheral Nerve Repair at the Fascicular Level.

In section VIII. **Properties of Muscle, B. Muscle Contraction:** Automatic Decomposition of the Electromyogram; Quantitative Analysis of the Surface Electromyogram; and A Smart Trigger for Real-Time Neuroelectric Spike Classification.

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 1. General:** Development of a Visual Evaluation and Training Book - The Vet Book; QUO VADIS: Voice-Output Questionnaire Administrator.

In section XIII. **Sensory Aids A. Blindness and Low Vision, 3. Reading Aids:** Tactile Graphic Braille Display; Establishing Design/Operational Features for Portable Blind Reading Aids.

In section XIII. **Sensory Aids, C. Speech Impairment:** DEXTER — A Mechanical Finger-Spelling Hand for the Deaf-Blind; Computer-Aided Visual Communication for Severely Impaired Aphasics.

In section XVI. **Miscellaneous:** Arm-Powered Bicycle for the Disabled; Dissemination of Rehabilitation Technologies; and Development of a Life Satisfaction Scale Applicable for People with Severe Disabilities.

Rehabilitation Research and Development Unit

Atlanta Veterans Administration Medical Center, Decatur, Georgia 30033
Franklyn Coombs, Director

The Rehabilitation R&D Unit in Atlanta has been designated to focus on technology applications in the aging disabled and the elderly veteran population. Currently, there are pilot studies in the following areas: observation and modification of wandering behavior in elderly nursing home patients; curvilinear synchronous motor for wheelchairs; sonic environmental control systems and wheelchair user survey; eye-tracking in elderly with disorientation; Syme prostheses ankle joint; hip abductor muscle force measure in post-surgical

hips; three-axis center of gravity and velocity measure in human gait; wheelchair ergometer with ECG feedback; and, head control units for nurse call/communication for ventilator dependent patients.

In addition, the following Merit Review projects are under way: the effect of electrical stimulation on osteoporosis; optimal features of large print computer displays for persons with visual impairment; EERG response to white noise; evaluation of Electronic Travel Aids (ETAs) for visually impaired individuals; ultrasonic measurement of peripheral blood flow; spherical electrical field measurements in visual stimulation; and, bathrooms and bathroom fixtures for elderly and disabled persons.

The following projects are reported in this issue:

In section IV. **Spinal Cord Injury, A. General:** Microwave Myelography: A Feasibility Analysis.

In section IV., **F. Environmental Control Systems for the Severely Disabled:** Design of Showers and Bathing Fixtures for Disabled and Elderly Veterans.

In section VI. **Biomechanics, A. Joint Studies, 1. General:** Biomechanical Studies of Bones and Joints.

In section VII. **Wound and Fracture Healing:** Electrical Stimulation for Augmentation of Wound Healing.

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 1. General:** Assessment of the Spatial and Temporal Characteristics of Vision as a Function of Age; The Correlation of Retinal Sources with the Electroretinogram.

In section XIV. **Head Trauma and Stroke:** Memory Remediation in Older Adults: A Computerized Interactive System.

In section XV. **Geriatrics:** Memory Remediation in Older Adults: A Computerized Interactive System; Bicycle Ergometer with Computer-Controlled Resistance and Video Display.

The following VA Medical Centers have reported work sponsored by the Rehabilitation Research and Development Service.

(Note: Centers are listed alphabetically by state)

VA Medical Center
Birmingham, AL 35233

In section XIII. **Sensory Aids, C. Speech Impairment:** Efficacy of Remote Treatment of

Aphasia by Tel-Communicology.

VA Medical Center
Little Rock, AR 72205

In section XI. **Low Back Pain: ND: YAG Laser Effect on Spinal Discs and Nerves.**

VA Medical Center
Tucson, AZ 85723

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 1. General: Limb Viability: Vascular Reconstruction and Amputation Surgery.**

VA Medical Center
La Jolla, CA 92103

In section VII. **Wound and Fracture Healing: Evaluation of Tubular Internal Fixation Plate for Fracture Management; Biomechanical Considerations of Metal and Composite Materials for Bone Fracture Fixation Plates.**

In section IX. **Ligaments and Tendons: Tensile Properties of the Medial Collateral Ligament as a Function of Age; Effects of Postmortem Storage by Freezing on Ligament Tensile Behavior; and Structural and Mechanical Behaviors of Tendons and Ligaments**

VA Medical Center
Loma Linda, CA 92357

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 2. Below-Knee: Optimum Prosthetic Foot Characteristics for the Dysvascular Below-Knee Amputee.**

In section VI. **Biomechanics, C. Human Locomotion and Gait Training: Weight Transfer Using Biofeedback**

VA Medical Center
Long Beach, CA 90822

In section XIII. **Sensory Aids, C. Speech Impairment: Effects of Real-Time Biofeedback on Dysarthric Speech.**

Wadsworth VA Medical Center
Los Angeles, CA 90073

In section III. **Total Joint Replacement and Other Orthopaedic Implants, B. Hip: Total Hip Biotelemetry.**

Brentwood Division, West Los Angeles VA Medical Center
Los Angeles, CA 90073

In section XVI. **Miscellaneous: Interpersonal Problem Solving by the Mentally Ill: Video-Assisted Technology for Training Social Skills; Training Schizophrenic Patients in Medication Management; and Training Chronic Mental Patients in Social and Independent Living Skills.**

VA Medical Center
Martinez, CA 94553

In section XIII. **Sensory Aids, B. Deafness and Hearing Impairment: Using a Psychophysical Model to Design Hearing Aids for Sensorineural Hearing Loss.**

In section XVI. **Miscellaneous: Rehabilitation of Neurogenic Communicative Disorders in Remote Settings.**

VA Medical Center
San Diego, CA 92161

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 1. General: The Effect on Gait Using Various Ankle-Foot Devices.**

In section I., **B. Lower Limb, 2. Below-Knee: Analysis of Below-Knee Suspension Systems: Effect on Gait.**

In section III. **Total Joint Replacement and Other Orthopaedic Implants, A. General: Implant Fixation by Post-Insertion Pressurization of Polymethylmethacrylate.**

In section VI. **Biomechanics, C. Human Locomotion and Gait Training: Foot Interface Pressure Study.**

In section IX. **Ligaments and Tendons: Structural and Functional Properties of Normal and Repaired Ligaments.**

VA Medical Center
San Francisco, CA 94121

In section II. **Orthotics: Molded Shoe.**

In section III. **Total Joint Replacement and Other Orthopaedic Implants, A. General: The Efficacy of Radiolucent Low Modulus Total Hip Surface Replacement.**

In section XIV. **Head Trauma and Stroke: Pharmacological Therapies in Central Nervous System Injury; Comparing Rat Brain Pathways**

from Normal and Transplanted Motor Cortex.

In section XVI. **Miscellaneous: Diabetic Neurotrophic Ulceration: Screening and Prevention Utilizing Aesthesiometry; Thermographic/Spectroscopic Comparison of Soaks, Exercise and Trental™ on Diabetic Feet.**

VA Medical Center
Sepulveda, CA 91343

In section XV. **Geriatrics: Falls in the Elderly: A Randomized Study of Intervention and Impacts.**

VA Medical Center
Denver CO 80220

In section I. **Amputations and Limb Prostheses, C. Upper Limb, 1. General: Implementation of Extended Physiological Proprioception for Prosthesis Control.**

In section XIII. **Sensory Aids, C. Speech Impairment: The Application of Microcomputers for the Treatment of Aphasic Adults.**

In section XV. **Geriatrics: Iatrogenic Disease in Hospitalized Elderly Veterans.**

VA Medical Center
Eastern Blind Rehabilitation Center, West Haven, CT 06516

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 2. Mobility Aids: Clinical Application Study of Training Techniques and Devices for the Blind.**

In section XIII., **B. Deafness and Hearing Impairment: Clinical Trials with the Cochlear Implant Prosthesis: Speech and Voice Characteristics (Part I); Clinical Trials with the Cochlear Implant Prosthesis: Speech and Voice Characteristics (Part II).**

VA Medical Center
Gainesville, FL 32602

In section III. **Total Joint Replacement and Other Orthopaedic Implants, B. Hip: Quantitative Analysis of the Effect of Total Hip Arthroplasty on Stress and Strain in the Human Pelvis.**

In section XVI. **Miscellaneous: Computerized Treatment of Acquired Reading Disorders.**

VA Medical Center
Miami, FL 33125

In section IV. **Spinal Cord Injury, A. General: The Use of EMG Biofeedback and Functional Electrical Stimulation in Spinal Cord Injury.**

VA Medical Center
Atlanta, GA 30033

In section IV. **Spinal Cord Injury, G. Wheelchairs, Including Seating Systems: Development of a Linear Synchronous Motor for Wheelchair Use.**

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 2. Mobility Aids: SONA-ECS; SONA-Sonic Orientation and Navigational Aid.**

In section XIII., **A. Blindness and Low Vision, 3. Reading Arts: Human Factors Considerations in the Design of Large Print Visual Display Units.**

VA Medical Center
Augusta, GA 30910

In section I. **Amputations and Limb Prostheses, A. General: Thermographic and Electromyographic Correlates of Stump and Phantom Limb Pain; Psychological Factors Influencing Chronic Phantom Limb Pain: Analysis of the Literature and a Survey of Locus of Control.**

In section IV. **Spinal Cord Injury, B. Medical Treatment: Differences Between Chest Heat Patterns Shown by Complete and Incomplete Spinal Cord Injured Veterans.**

In section XIII. **Sensory Aids, B. Deafness and Hearing Impairment: Electroacoustic and Behavioral Studies of the Effect of Ear Impedance on Hearing Aid Performance; Studies in Acoustic Feedback in Hearing Aids.**

VA Medical Center
Des Moines, IA 50310

In section XVI. **Miscellaneous: Rehabilitation of Neurogenic Communicative Disorders in Remote Settings.**

VA Medical Center
New Orleans, LA 70146

In section III. **Total Joint Replacement and Other Orthopaedic Implants, A. General: The Efficacy of Radiolucent Low Modulus Total Hip Surface Replacement; Orthopedic Implant**

Retrieval and Analysis; and The Mechanical Properties of Porous-Coated Orthopaedic Alloy.

VA Medical Center
Baltimore, MD 21218

In section IV. **Spinal Cord Injury, B. Medical Treatment:** Clinical Evaluation of an External Device for Urinary Care in Incontinent Women.

VA Medical Center
Boston, MA 02108

In section XIII. **Sensory Aids, B. Deafness and Hearing Impairment:** Direct Measurement of Loudness Recruitment in Hearing-Impaired Veterans.

VA Medical Center
West Roxbury, MA 02132

In section II. **Orthotics:** Design of External Joint Assemblies Using CAD-CAM Techniques.

In section III. **Total Joint Replacement and Other Orthopaedic Implants, C.. Knee:** Investigation of a Simplified Internal Knee Prosthesis.

VA Medical Center
Togus, ME

In section XIV. **Head Trauma and Stroke:** Efficacy of Multiple Input Phoneme Therapy in the Treatment of Severe Expressive Aphasia.

VA Medical Center
Ann Arbor, MI 48105

In section IV. **Spinal Cord Injury, I. Functional Electrical Stimulation, 4. Other:** Electrical Muscle Stimulation for the Prevention of Pressure Sores: 1) Pressure Studies; Electrical Muscle Stimulation for the Prevention of Pressure Sores: 2) Ultrasonic Shape Imaging Studies.

VA Medical Center
Columbia, MO 65201

In section XIII. **Sensory Aids, C. Speech Impairment:** Application of Microcomputers for the Treatment of Aphasic Adults.

VA Medical Center
St. Louis, MO 63125

In section XIV. **Head Trauma and Stroke:** Efficacy of Computer-Assisted Rehabilitation; The Impact of NMR on the Management of Brain Lesions.

In section XV. **Geriatrics:** Adjustment and Rehabilitation of Chronic Illness Among Older Veterans.

In section XVI. **Miscellaneous:** Reliability and Validity of CT and NMR.

VA Medical Center
Omaha, NE 68105

In section VII. **Wound and Fracture Healing:** Bioelectricity in Fracture Healing.

VA Medical Center
East Orange, NJ 07019

In section X. **Arthritis:** The Use of Biofeedback and Cognitive Behavioral Psychotherapy in the Treatment of Severe Rheumatoid Arthritis Patients: A Controlled Evaluation.

VA Medical Center
Reno, NV 89520

In section XIII. **Sensory Aids, C. Speech Impairment:** Drawing: Use as Communicative Aid with Aphasic and Normal Adults.

VA Medical Center
Albany, NY 12208

In section XVI. **Miscellaneous:** Cardiac Rehabilitation: Preliminary Results and Treatment Efficacy.

VA Medical Center
Bronx, NY 10468

In section IV. **Spinal Cord Injury, E. Communication Methods and Systems for the Severely Disabled:** Capuchin Monkeys as Aids for the Severely Disabled.

VA Medical Center
Castle Point, NY 12511

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 1. General:** Use of Cutaneous Pressure Photoplethysmography in Managing Peripheral Vascular Occlusive Disease.

In section III. **Total Joint Replacement and Other Orthopaedic Implants, A. General:** Biomechanics of Bone Resorption/Regeneration at a Bone Implant Interface.

In section IV. **Spinal Cord Injury, B. Medical Treatment:** A Feasibility Study on Detection of Impending Pressure Sores Using Ultrasound.

In section IV., **G. Wheelchairs, Including**

Seating and Controls: Seat Cushions for the Paralyzed.

In section VII. **Wound and Fracture Healing: Stimulation of Repair of Cortical Bone Transplants by Implantation of Piezoelectric Materials: A Development Study.**

In section XVI. **Miscellaneous: Noninvasive Quantification of Venous Reflux; Predicting the Success of Lumbar Sympathectomy in Patients with Severely Ischemic Foot; and A Program for Evaluating the Dysvascular Patient.**

VA Medical Center
New York, NY 10001

In section IV. **Spinal Cord Injury, G. Wheelchairs, Including Seating and Controls: Seat Cushions for the Paralyzed.**

VA Medical Center
Cleveland, OH 44106

In section IV. **Spinal Cord Injury, I. Functional Electrical Stimulation, 2. Upper Limb Applications: Functional Neuromuscular Systems for Upper Extremity Control.**

In section IV., I. **Functional Electrical Stimulation, 3. Upper Limb Applications: Walking Restored in Paralyzed Man Using Electronic Orthotics.**

VA Medical Center
Dayton, OH 45428

In section IV, **Spinal Cord Injury. A. General: Fitness Improvements and Physiological Responses to FES Exercise.**

In section IV., I. **Functional Electrical Stimulation, 4. Other: Fitness Improvements and Physiological Responses to FES Exercise.**

VA Medical Center
Oklahoma, OK 73104

In section IV. **Spinal Cord Injury, F. Environmental Control Systems for the Severely Disabled: Environmental Control Units for Disabled Veterans.**

VA Medical Center
Portland, OR 97207

In section XV. **Geriatrics: The Social and Medical Effects of Amputation on Elderly Veterans.**

VA Medical Center
Lebanon, PA 17042

In section II. **Orthotics: The Role of Pressure Distribution Measurement in Diabetic Foot Care.**

VA Medical Center
Philadelphia, PA 19104

In section I. **Amputations and Limb Prostheses, A. General: Fluorometric Quantification of Low-Dose Fluorescein; Delivery to Predict Amputation Healing; Fiberoptic Fluorimetry as a Useful Adjunct in Determining Lower Extremity Amputation Level; Determining the Need or Level of Amputation by Assessing Nutritive Skin Blood Flow; and Myoelectrically-Controlled Above-Knee Prosthesis.**

In section I. **C. Upper Limb, 1. General: Cosmetic Covers for Upper Extremity Prostheses (Male/Female).**

In section XVI. **Miscellaneous: Skin Blood Flow by Helium Flux Effect of Skin Temperature; Comparison of Helium Flux and Laser Doppler Skin Blood Flow Measurements: Effect of Skin Temperature; Comparison of Helium Flux and Xenon Washout of Skin Blood Flow Measurements in Man; and Evaluation of Cutaneous Blood Flow in Dysvascular Patients and Normals: Laser Doppler and Fluorometry Compared.**

VA Medical Center
Pittsburgh, PA 15206

In section X. **Arthritis: Ferrographic and Biochemical Analysis of Wear Particles in Human Joints**

In section XIII. **Sensory Aids, C. Speech Impairment: Experimental Analysis of Acquisition and Generalization of Syntax.**

In section XV. **Geriatrics: Computer-Based Expert System for Geriatric Psychiatry.**

William Jennings Bryan Dorn VA Medical Center
Columbia, SC 29203

In section III. **Total Joint Replacement and Other Orthopaedic Implants, A. General: Expert Manufacturing System for Custom Prosthesis.**

In section XIII. **Sensory Aids, B. Deafness and Hearing Impairment: Implementation of Digital Measurement of Aural Acoustic Immittance.**

VA Medical Center
Memphis, TN 38104

In section IV. **Spinal Cord Injury, G. Wheelchairs, Including Seating and Controls: Mini Litters: A Specialized Mobility Construction for Spinal Cord Injured Patients**

with Bilateral Lower Limb Amputations and Diminished Seating Capacity.

In section XIII. **Sensory Aids, C. Speech Impairment:** Measurement and Prediction of Benefit from Amplification.

In section XV. **Geriatrics:** Discharged Elderly Patients from the Memphis VA Medical Center Nursing Home Care Unit (NHCU): A Followup Study; Impact of a Geriatric Assessment and Rehabilitation Unit on Subsequent Health Care Expenditures; and Modeling Length of Stay for the Hospitalized Elderly.

VA Medical Center
Nashville, TN 37203

In section VI. **Biomechanics, A. Joint Studies, 2. Lower Limb:** Pathokinesiology of Anterior-Cruciate-Ligament Deficiency.

In section VI., **E. Other:** Bone In Vivo and In Vitro Stress and Strain Patterns: Influence of Age and Activity.

VA Medical Center
Dallas, TX 75216

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 1. General:** Aerobic Training Improves Cardiovascular Fitness and Increases Efficiency of Walking in Lower Limb Amputees.

In section VII. **Wound and Fracture Healing:** Quantifying Fracture Healing in Impulse Transfer Functions.

VA Medical Center
Houston, TX 77211

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 1. General:** Automated Fabrication of Lower Extremity Prosthetic Sockets.

VA Medical Center
San Antonio, TX 78285

In section XIII. **Sensory Aids, C. Speech Impairment:** Maxillofacial Prosthetic Management of Neurogenic Tongue Dysfunction.

VA Medical Center
Temple, TX 76501

In section XIII. **Sensory Aids, B. Deafness and Hearing Impairment:** Development of a Digital Hearing Aid and Fitting Procedure;

Development of Materials for Computer-Assisted Instruction in Lipreading.

VA Medical Center
Richmond, VA 23249

In section XIII. **Sensory Aids, B. Deafness and Hearing Impairment:** Changes in Frequency Organization of the Cochlea During Aging.

VA Medical Center
Salem, VA 24153

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 2. Below-Knee:** Sockets with Flexible Brims; Adjustable Below-Knee Socket.

In section V. **Functional Assessment:** Ambulatory Physiological Monitoring Device.

VA Medical Center
White River Junction, VT 05001

In section XIV. **Head Trauma and Stroke:** Community Study: Stroke Rehabilitation Using Volunteer Help; Community Model: Rehabilitation of Older Adults with Brain Injuries.

VA Medical Center
Seattle, WA 98108

In section III. **Total Joint Replacement and Other Orthopaedic Implants, A. General:** Evaluation of Total Joint Implant Loosening Using X-Ray Photogrammetry.

In section IV. **Spinal Cord Injury, B. Medical Treatment:** The Spasticity of Spinal Cord Injury.

In section VII. **Wound and Fracture Healing:** Altered Collagen and Wound Metabolism in Non-Healing Diabetic Ulcers.

In section XIV. **Head Trauma and Stroke:** Evaluation of Family Stroke Education.

In section XV. **Geriatrics:** Nutrition and Health in the Aging Veteran Population.

VA Medical Center
Milwaukee, WI 53295

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 1. General:** Pilot Studies in the Area of Sensory Substitution.

In section XVI. **Miscellaneous:** Age-Related Changes in Sensory-Motor Performance; Development of a Sensory Substitution System for the Insensate Foot.

The following institutions have reported work sponsored in part or in full by the Rehabilitation Research and Development Service.

Bioengineering Alliance of South Carolina (Co-Sponsor)

Clemson University, Clemson, SC 29634

In section III. **Total Joint Replacement and Other Orthopaedic Implants, A. General:** Expert Manufacturing System for Custom Prosthesis; Porous Polyethylene as a Reconstructive Material.

In section VI. **Biomechanics, C. Human Locomotion and Gait Training:** Effect of Shock-Absorbing Materials on Heel-Strike Forces.

Special Team for Amputation and Mobility Prosthetics/Orthotics (Co-Sponsor)

VA Medical Center, Dallas, TX 75216

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 1. General:** Aerobic Training Improves Cardiovascular Fitness and Increases Efficiency of Walking in Lower Limb Amputees.

U.S. Public Health Service, Maternal and Child Health Division (Co-Sponsor)

Rockville, MD 20857

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 2. Below-Knee:** ISNY Below-Knee Flexible Socket.

University of Utah School of Medicine (Co-Sponsor)

Salt Lake City, UT 84132

In section III. **Total Joint Replacement and Other Orthopaedic Implants, B. Hip:** Skeletal Aging and Disease in Failure of Hip Surface Replacement.

Central Institute for the Deaf

St. Louis, MO 63110

In section XIII. **Sensory Aids, B. Deafness and Hearing Impairment:** Development of a Digital Hearing Aid and Fitting Procedure.

Georgia Institute of Technology

Atlanta GA 30332

In section XIII. **Sensory Aids, A. Blindness and Low Vision, 1. General:** Rabbit ERG

Responses to White-Noise Modulated Stimuli; The Correlation of Retinal Sources with the Electroretinogram.

Johns Hopkins University

Applied Physics Laboratory, Laurel, MD 20707

In section IV. **Spinal Cord Injury, G. Wheelchairs, Including Seating and Controls** Wheelchair Control and Robot Arm/Work Table Systems for High Spinal Cord Injured Persons.

NeuroMuscular Research Center

Boston University, Boston, MA 02215

In section VI. **Biomechanics, E. Other:** Visuomotor Effects on Postural Sway.

In section VIII. **Properties of Muscle, B. Muscle Contraction:** Motor Control in Movement Disorders.

In section IX. **Ligaments and Tendons:** Muscle Fatigue and Back Pain

New York University Medical Center

New York, NY 10016

In section IV. **Spinal Cord Injury, I. Functional Electrical Stimulation, 2. Upper Limb Applications:** EMG as Force-Feedback in Closed-Loop Functional Electrical Stimulation.

New York University Postgraduate Medical School

New York, NY 10016

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 2. Below-Knee:** ISNY Below-Knee Flexible Socket.

Northwestern University

Chicago, IL 60611

In section I. **Amputations and Limb Prostheses, B. Lower Limb, 2. Below-Knee:** Computer-Aided Analysis of Below-Knee Socket Pressure.

In section I., **C. Upper Limb, 1. General:** Design of Prehension Systems for Upper-Limb Amputees; Position-Servo of Upper-Limb-Powered Prostheses.

In section I., **C. Upper Limb, 2. Below-Elbow:** Below-Elbow Prosthetic System.

Prosthetics Research Laboratory

Northwestern University, Chicago, IL 60611

In section I. **Amputations and Limb**

Prostheses, B. Lower Limb, 1. General:
Computer-Aided Alignment of Lower Limb
Prostheses and "Expert" Systems.

Rusk Institute of Rehabilitative Medicine,
New York University Medical Center, New
York, NY 10016

In section I. **Amputations and Limb
Prostheses, B. Lower Limb, 3. Above Knee:**
Geriatric Prosthetics: Design and Development
of an Improved Above-Knee Socket.

University of California
San Diego, CA 92103

In section VII. **Wound and Fracture
Healing:** Evaluation of Tubular Internal
Fixation Plate for Fracture Management;
Biomechanical Considerations of Metal and
Composite Materials for Bone Fracture
Fixation Plates.

In section IX. **Ligaments and Tendons:**
Tensile Properties of the Medial Collateral
Ligament as a Function of Age; Effects of
Postmortem Storage by Freezing on Ligament
Tensile Behavior; and Structural and
Mechanical Behaviors of Tendons and
Ligaments.

University of Hawaii at Monoa
Honolulu, HI 96822

In section XIII. **Sensory Aids, A. Blindness
and Low Vision, 1. General:** Computer Vision
for the Blind.

University of South Carolina
Columbia, SC 29208

In section XIII. **Sensory Aids, B. Deafness
and Hearing Impairment:** Electroacoustic and
Behavioral Studies of the Effect of Ear
Impedance on Hearing Aid Performance.

**University of Southern California, Los
Angeles, and Rancho Los Amigos Medical
Center**
Downey, CA 90242

In section I. **Amputations and Limb
Prostheses, B. Lower Limb, 2. Below-Knee:**
Optimum Prosthetic Foot Characteristics for
the Dysvascular Below-Knee Amputee.

In section VI. **Biomechanics, C. Human
Locomotion and Gait Training:** Gait, Balance

and Symmetry in Hemiplegia: An Analysis
With and Without Biofeedback.

**University of Texas at Arlington, Arlington,
TX 76019 and University of Texas Health
Science Center at Dallas, Dallas, TX 75235**

In section XI. **Low Back Pain:**
Myoelectrical Assessment of Human Lumbar
Muscle Function.

**University of Texas Health Science Center at
Dallas**
Dallas, TX 75235

In section VI. **Biomechanics, E. Other:**
Enhancement of Union of Segmental Defect
Fractures.

University of Washington
Seattle, WA 98195

In section I. **Amputations and Limb
Prostheses, B. Lower Limb, 1. General:** Clinical
and Laboratory Study of Amputation Surgery
and Rehabilitation.

In section VII. **Wound and Fracture
Healing:** Morphological and Clinical Studies of
Microwounds in Ischemic Human Tissue;
Transcutaneous Oxygen Tension as Prediction
of Wound Healing.

University of Wyoming
Laramie, WY 82071

In section XIII. **Sensory Aids, B. Deafness
and Hearing Impairment:** Studies in Acoustic
Feedback in Hearing Aids.

Washington University
St. Louis, MO 63130

In section XIII. **Sensory Aids, B. Deafness
and Hearing Impairment:** Development of a
Digital Hearing Aid and Fitting Procedure.

Yale Medical School
New Haven, CT 06510

In section VI. **Biomechanics, B. Spine:**
Mechanisms of Cervical Spine Injuries.

Yerkes Primate Research Center
Atlanta, GA 30030

In section IV. **Spinal Cord Injury, B.**
Medical Treatment: Evaluation and
Rehabilitation of Reproductive Function in
Paraplegia.

Contributor Index

Abraham G 237
Abrahamson JE 326
Acimovic-Janezic R 163
Ackerman TM 305
Adkisson J 286
Affleck GG 261
Aizcorbe O 16, 186
Akeson WH 240, 241, 254,
255, 256
Alazraki NP 56
Aldrich FK 308
Alexander GC 330
Alexander J 73
Alfonso MP 374
Alford W 275
Alfred W 77
Allen EJ 116
Amiel D 240, 254
Amster WW 333
Anderson AD 392
Anderson EG 196
Anderson G 13
Anderson LL 123
Anderson R 53
Angliss V 24, 33
Apostolos MK 140, 141
Applebaum KE 257
Applegate WB 358, 365
Arenberg D 364
Arnold BR 397
Axelson P 382, 383
Aylor J 144
Ayyar DR 66

Bach-y-Rita P 302, 394
Bagley M 284
Bahrani A 58
Baker L 163
Bakshi KR 10
Baldasare J 309
Baranowski TJ 180
Baratta R 167, 197, 250
Barnes JW 358

Barnes L 357
Bartley E 2
Bass RM 145, 305
Baumgardner JE 11, 376, 377
Beaupre G 62, 228, 231
Bechtel R 19
Beck P 360
Becker G 300, 344, 362
Beckers PJ 379
Behbehani K 189
Benko H 235
Bennett L 149
Berg EW 46, 61, 204
Berger N 17
Berndt RS 346
Bess JC 333
Beveridge KD 63
Beyer R 135
Bholet D 359
Binder LM 344
Birch G 122
Blanchard EB 257
Blocker WA 5
Blow FC 357, 358, 365
Blum C 351
Boenick U 117, 156
Boileau RA 83
Bolam JM 84, 171
Boom HBK 12, 178
Boop WC 273
Boosfield CHM 156
Booth AM 81
Bornhoeft DM 384
Boscardin JB 269
Bosiers W 315
Bosshard RG 176
Bostrom JA 121
Boyd LH 293
Boyet K 287, 288
Brabyn JA 278, 279, 327
Brackett J 125
Braida LD 316
Brandenburg S 395

Branson PJ 44
Bregman BS 104
Bresler MI 142
Brighton CT 236
Britell CW 160
Brooks SV 182, 183
Brousseau DA 2
Brown H 2
Brown JW 351
Brown R 81
Brubaker C 144
Brucker BS 66
Brunner C 258
Bruno GM 1
Brunski J 48
Brutsaert DL 378, 379
Bucholz RW 232
Buck D 350
Buckley CE 143
Buckley J 148
Budde JF 399
Bui KD 29
Burgess EM 14, 234
Burgess E 233
Burn TG 150
Burnet D 300
Burns JR 85
Bushnaq R 221

Caler W 212
Calia FM 88
Cameron W 122
Camp JF 255
Campos RJ 166
Cannon DJ 139
Capps C 288
Cardi M 150, 151
Cardus D 77
Carlson LE 32
Carmichael TW 270
Carollo JJ 191
Carter D 47, 55, 62, 64, 211,
212, 213, 214, 215, 228, 231

- Carter RE 76
Cavalier AR 87
Cavanagh P 35
Cederna PS 182, 183
Cerullo L 29
Chakkalakal DA 229
Chao EY 52
Chase R 65, 128
Chen S 285
Childress DS 18, 26, 111, 26,
27, 28, 32, 206
Chuinard R 197
Chwialkowski M 189
Claes GA 379
Clark BE 276
Claus-Walker J 79, 93
Clinton RG 197
Cochran GVB 48, 96, 151, 230
Cochran T 59
Cohen B 371
Collins M 340
Collins SR 167
Connolly JF 229
Convery FR 50
Cook D 288
Cook SD 50, 53
Cooke FW 47
Cooper D 367
Cooper JC 364
Cooper WE 314
Corso AM 308
Courington S 300
Courtney JM 237
Coutts RD 240, 241
Cox RM 330
Crago PE 169
Crimmins EM 362
Crowgey SR 67, 228
Cruts HEP 12
Cullen JM 106
Cummins K 194, 237
Curry SH 338
Curtis GE 134, 135, 140
Cutshall TA 204

Dabney RL 188
Daly SS 374

D'Ambrosia R 37, 197, 198,
250
Daniels AU 56
Danopoulos D 181
Davey KR 145, 297
Davis GM 167
Davis R 175
Deal JL 392
DeAndrade R 197, 359
Degood DE 269
Deivanayagam S 270
De l'Aune R 304, 309
De Luca CJ 221, 242, 244, 245,
246, 247, 250, 251, 254
Delehanty A 175
Delhez L 371
Demer JL 294
de Troyer A 95, 371
Dettmann MA 371
Devellis B 265
DeVivo MJ 70
de Vries J 12
DeWinter H 252
Dimitrijevic MR 166
Donahoe CP 385
Donnelly A 24
Donovan WH 76
Dooley RL 46
Dorfman L 194, 247, 248, 249
Dougherty DR 5
Douglas R 172
Dourov N 401
Doyle PJ 336
Dunlop RJ 326
Dunn M 390
Duranceau J 202
Dutton DB 259
Dvorak DJ 22
Dye CJ 356

Eckhouse R 175
Eckman TA 387, 388
Edgerton RB 363
Edwards L 133
Efron R 313
Egolf DP 315
Elasky N 44, 61
Eng C 40

Engel BT 365
Engel GL 311
Engelbretson AM 311
Engelmeier 171
Erb RA 29
Ernst JL 84
Estenne M 95, 371
Euller KC 374
Evans CH 268
Evans JH 237, 271, 398
Evans M 380
Evans RL 349
Ewald F 59

Faden AI 342
Fahrer M 24, 33
Faulkner V 6, 7, 8
Fawcett J 149
Feldman S 82, 94
Felici F 247
Ferguson S 292
Ferguson-Pell MW 98, 150,
151
Figoni SF 83
Fine PR 70
Finnerty-Fried P 396
Fisher WE 40, 146, 147, 151
Fishman S 17
Fletcher J 349, 375
Flevaris-Phillips C 322
Flowers W 24
Ford K 281, 282, 289
France EP 56
Frank CB 255
Friedman CP 265
Friedman HI 47
Fries JF 259, 263
Fruin RC 171
Fuhrer M 76
Fyhrie D 55, 213, 215

Galante SR 11, 376, 377
Gall N 6, 7, 8
Gambert SR 361
Garber S 75
Garcia DM 52
Gardner ER 207
Garfin S 240, 254

- Garrett RE 277, 374, 383
 Garrison L 19
 Gaylor JDS 237
 Gelberman R 254
 Gerber LH 267
 Geruschat D 304
 Gick R 275
 Giesen JM 281, 282, 288, 289
 Gilbert DJ 333
 Gilden D 278, 279, 327, 328
 Gillebert TC 379
 Gilman S 319
 Gilmore C 330
 Gilmore LD 117, 201, 243, 251, 252, 254
 Gilstad DW 380
 Gimbrere M 136
 Gira C 212
 Glaser RM 167, 179
 Glass D 66
 Glass K 138
 Glatt S 371
 Goeminne HM 378
 Goeppinger J 259
 Golbranson FL 9, 18, 205
 Goldberg J 294
 Goldman H 348
 Golper LA 344
 Gomez G 246
 Gomez MA 255
 Goodenough-Trepagnier C 110, 327, 353
 Goodrich GL 298, 299, 306, 307, 390
 Gordon ME 203, 216
 Gordon WA 347
 Goshgarian HG 100
 Gottschalk FA 12
 Gozal D 35
 Graf PM 41
 Grahn EC 22, 26, 27, 28, 32
 Gransbury K 383
 Gratzner M 171, 179
 Graves DJ 11, 376, 377, 378
 Graves WH 282, 284, 286, 287, 288
 Green BA 66
 Greenidge N 273
 Gregorio T 75
 Griffith S 38
 Gronley J 19
 Gruner JA 161
 Gupta SC 167
 Gurbani N 163
 Gurewitsch AD 392
 Habisawa S 98
 Hall K 138
 Halstead L 94
 Hamati FI 43
 Hamblen DL 58
 Hammond KW 366
 Hanagud SV 197
 Hannon C 367
 Harrington RM 234
 Harris JD 40, 148, 381
 Harrison W 196
 Harte C 154
 Haucke M 283
 Hayes WC 236
 Heckathorne CW 27, 28, 111
 Heidbreder AF 311
 Heilporn A 95, 371, 401
 Hellman RP 320
 Henry RE 13
 Hentz VR 237
 Hermens HJ 178
 Herrera E 137, 138, 139
 Hickling EJ 257, 374
 Hillstrom H 23
 Hofmann AA 56
 Hogan N 30
 Holewski JJ 393
 Holloway KJ 134, 137
 Hollyfield R 281, 303
 Holmes W 127
 Holmok CL 66
 Homan HR 259
 Horn BKP 302
 Horrocks LA 69
 Houle JD 101
 Howard J 248
 Hoy M 199, 216
 Huang CT 89, 93
 Huddleston T 208
 Huisman K 12
 Hulsebosch CE 102
 Hurwitz DE 150, 151
 Hutchins SE 346
 Ignagni AR 168
 Inigo R 144
 Jabre JF 245
 Jaeger RJ 171, 179
 Jaffe DL 118, 299, 306, 328
 Jahnigen DW 367
 James WV 58, 154, 208
 Jameson JW 142
 Jampolsky A 278, 279, 327
 Jansen EC 203
 Jaros LA 114, 152, 341
 Jenkins HA 294
 Jinks A 340
 Jocz WS 29
 Johnson DE 88
 Johnson DR 160
 Johnson KD 226
 Jones N 277
 Jones RE 232
 Josephson K 370
 Judge D 2
 Kabo JM 58
 Kadaba MP 96
 Kahanovitz N 271, 273
 Kalderon N 102
 Karas W 33
 Kashner M 355
 Kauzlarich JJ 144
 Kearns KP 333
 Keith MW 3, 162, 169, 193
 Keller TS 220
 Kelly GW 58, 145, 305, 310
 Kennedy J 211
 Kester MA 53
 Kett RL 113, 152, 182
 Kezdi P 181
 Khan TA 106, 107
 Khang G 176
 Kimbrough EE 61
 King PS 357
 Kirchner JC 322
 Kirsch NL 341
 Kirsch NL 341

- Klinenberg E 44
Knight GW 52, 269
Knight RT 392
Koblasz A 296, 297, 359
Koester DJ 29, 113
Kondraske GV 188, 189, 190, 191, 270
Kopra LL 326
Kopra MA 326
Kosorok V 235
Krebs D 17
Krick H 26, 27, 28
Krouskop TA 2, 5
Kuhn GF 318
Kukes GD 99
Kuncir EJ 9, 18, 205
Kurland LT 264
Kushler C 324
- Laborde M 166
Laederach JC 148
LaForce FM 367
Lamb AM 288
Lambert R Jr 300
Larrivee D 100
Larsen JR 83
Larsen TK 203
Larson P 172
Larson VD 314, 315
Laura PAA 42, 157
Lautenschlager EP 43
Lawrence KL 232
LeBlanc M 25
Leader B 351
Leder SB 322
Lee BY 14, 149, 372, 373, 386
Lee C 111
Lee HS 132
Leedom R 115, 340
Leff HS 396
Lehmkuhl LD 74
Lehneis HR 21
Leibowitz LJ 28, 111
Leibowitz L 4
Leifer L 119, 128, 129, 141, 381, 382
Leung P 265
Levine SH 110
- Levine SP 29, 113, 114, 152, 182, 183, 341
Levine W 217, 218, 219
Levitt H 318
Lewis D 115
Lewis JL 44, 46, 61
L'Hermite M 401
L'Hermite-Baleriaux M 401
Liang MH 266
Lieberman RP 195, 385, 387, 388
Lieber RL 184
Light RW 336
Lindner M 371
Lippert FG III 49
Lippiello L 229
Lipton JP 261
Little JW 85
Liuzzi FJ 103
Lloyd LK 86, 181
Lorenz M 269
Lou E 223
Loverso FL 331
Lubeck DP 259
Ludlow L 300
Lundin FJ 330
Lyon JG 332
Lyon S 287, 288
- MacGregor J 187
Machalow SD 284, 286
MacKay SJ 347, 348
Madson M 38
Maher M 126
Malassigne PM 121
Malezic M 235
Malone JM 13
Malzahn D 210
Mancano B 311
Mann RW 191, 200
Markowski J 84
Marmion S 283, 286, 287, 288
Marquet J 315
Marshall LF 339
Marsolais EB 171
Martin AJ 277
Martin DE 95
Martinson IM 262
- Masiello RD 150
Mason CP 161
Mason C 223
Massel HK 195
Massey BH 83
Mathsen DV 384
Matsen FA III 233, 234
Matsuzawa I 247
Maxson BJ 282, 283, 286
Mayer TG 270
Mazumdar J 275
McBroom L 285, 286
McCarthy C 242
McClellan AD 101
McGill K 247, 248, 249
McLaughlin RE 51
McLaurin CA 144
McNeal D 163, 164, 173, 207
McNeal LW 305, 310
McPhail J 176
Mears DC 268
Meenan RF 260
Mehr O 298
Mente P 46
Merletti R 242, 252
Michalowski SJ 128, 130, 131, 132, 133
Miller GJ 55
Milner P 322
Mineo BA 87
Minor MA 262
Mintz J 195
Mitchell MM 265
Miyamoto H 40
Mone M 401
Mooney V 188, 190, 270
Moore JW 52
Moreland JR 58
Moreno C 351
Morley RE 311
Morris AF 83
Mortimer IR 40
Mortimer JT 79
Moskowitz GD 23
Moss KM 394
Moyle DD 204
Mulrea KC 13
Mulvihill M 273

- Murphy R 125
 Myklebust BM 371
 Myklebust JB 371

 Nakai R 173
 Nation B 297
 Nava LC 42, 157
 Nemchausky BA 171, 179
 Neufeld GR 2, 10, 11, 376, 377, 378
 Nichols L 365
 Nicholson D 174
 Nicol AC 58, 63
 Noone G 275
 Nordin M 273
 Norton KJ 2
 Nosek MA 72, 108, 109, 372
 Nosse L 371
 Novak MA 43

 O'Brien JP 271
 O'Connell MP 311
 O'Leary A 258
 O'Neill H 97, 153
 O'Reilly JL 88
 O'Riain MD 31, 124, 157
 Ochs M 357, 365
 Officers E 315
 Olerud J 233, 234
 Orlando CA 255
 Orr JF 58, 154, 208
 Orr T 47, 64, 213
 Oster AM 325
 Ostrander LE 14, 372, 386
 Otto H 1126
 Overbury O 298
 Overton M 24

 Page CM 384
 Palmieri VR 151
 Panjabi M 202
 Park H 132
 Parker JC 262
 Parkin AJ 308
 Parnianpour M 273
 Patmont V 19
 Patrick JF 175
 Patwardhan AG 52, 269

 Paul JP 8, 10, 35, 58
 Paz-Alfonso M 257
 Pearlman RA 354
 Peckham PH 3, 62, 162, 169, 193
 Pecoraro RE 233
 Peeters S 315
 Pelker R 202
 Perlash I 95, 97, 128, 153, 173, 219
 Perlman SG 264
 Perry J 19, 174, 207
 Peterson JM 290
 Petrofsky J 172, 181
 Petty W 55
 Phillips C 172, 181
 Pikus A 365
 Pitetti KH 12
 Pitts L 80
 Plant G 325
 Poelemans KM 378
 Polizos T 44
 Popelka GR 311
 Popovic D 36
 Porter FI 294
 Powers DL 47
 Prasad C 82
 Prescott TE 331
 Price MB 394
 Pusakulich KM 330

 Quillman RD 298
 Quinn JA 11, 376, 377, 378

 Radcliffe DF 127
 Rademaker FE 378, 379
 Rakshit AK 224
 Rebersek S 184
 Reid WH 398
 Reilly CA 2, 10, 11, 376, 378
 Reisine ST 261
 Ribas-Cardus F 77
 Richards JS 90, 91
 Richardson F 322
 Richmond JR 189
 Riederer-Henderson MA 233
 Riesen AH 295
 Rinalducci EJ 280

 Rintala D 73
 Riso RR 168
 Rivera W 126
 Robbins AS 370
 Roberson J 180
 Roberts AB 2, 10, 11, 378
 Robinette LN 323
 Robinson CJ 84, 171, 179
 Rodell DE 355
 Rodriguez G 93
 Rogers CM 354
 Rosen J 237, 239
 Rosen MJ 187, 327, 353
 Ross DA 145, 305, 310
 Rossdeutscher W 117
 Rossman H 350
 Rothi LG 385
 Rovick J 38, 59
 Rowe PJ 58
 Rowell D 191
 Rowlingson JC 269
 Roy SH 117, 201, 221, 251, 254
 Rubel EW 321
 Rubenstein LZ 370
 Rubin G 17, 21
 Rudd AK 333
 Rudin N 117
 Ryals BM 321
 Rymer WZ 68

 Sabbahi M 223
 Sabelman EE 71
 Sacks AH 97, 219, 389
 Sakurai Y 40
 Saltzstein R 371
 Sandborn PM 53
 Sanders LJ 35
 Sanford MK 262
 Saunders MJ 333
 Scala J 245
 Schauer J 111
 Schmeisser G 155
 Schmitt S 288
 Schnur DS 18
 Schoutens A 401
 Schrager R 38
 Schulman B 370
 Schulz EM 300

Schwandt D 147, 381, 382
Scremin OU 69
Seamone W 155
Seeger BR 40, 127, 146, 147,
151, 170, 177, 275, 277, 374,
383, 384
Seery J 13
Servedio FJ 167
Shanbhag A 47
Sharkey PC 166
Sharp FR 343
Sharpe SM 67, 228
Shea A 222
Shenaut GK 392
Sherman CJ 1
Sherman RA 1, 84
Sherwood AM 166
Shiavi R 198
Shimazaki Y 40
Shindell S 390
Shoji H 197, 250
Shore P 297
Shulmann D 222
Shum L 120, 149
Sica DA 83
Silverman DG 2, 10, 11
Simmons FB 316
Simon HJ 313
Simon SR 266
Sison GFP 348
Skinner HB 50
Smith AD 354
Smith G 286
Smith JL 305
Smith SS 188, 190
Snell PG 12
Soboloff H 166
Solomonidis SE 8, 10, 35
Solomonow M 37, 166, 167,
197, 198, 250
Sonnier BJ 295
Sorensen CG 203
Sorensen L 360
Souter WA 63
Spector M 180
Spengler DM 220
Spens KE 325
Spitzer JB 322

Sprenkels H 252
Stabenow C 258
Stacy R 181
Staehlin JH 112, 126, 127, 275
Stamp W 144
Stashuk DW 244, 245, 246
Steege JW 44
Steele C 214
Steele RD 307, 334
Stefanovska A 235
Stelmack JD 358
Sterling HM 19, 207
Stern LM 170, 177, 276, 277
Stess RM 41
Stevens ER 338
Stover SL 86, 92
Strasburg D 365
Strauss MG 232
Stray-Gundersen J 12
Strelow ER 295
Strick PL 67
Stryzik JS 26, 27, 28, 32
Studebaker GA 317
Stulberg SD 44
Sullivan J 245
Suryaprasad AG 167, 179
Symons J 163, 174
Szary C 35
Szeto AYJ 116

Tabbador K 339
Taggart WG 77
Takacs H 286
Tanner C 47
Taylor H 158
Tenbrink TD 262
Tew AI 148, 380
Thacker J 144
Thomas KA 53
Thompson DJ 323
Thompson JD 78
Thongpreda N 53
Tidwell AA 333
Tiegermann VR 201, 251, 254
Till JA 336
Tillman HH 359
Tintner R 190
Tokimura K 40

Torburn L 19
Traylor DR 308
Tricot A 401
Trimble J 301, 358
Triolo RJ 23
Tu W 173
Turk R 235
Turner J 272

Vanderheiden GC 115
Vanderploeg RD 348
van Alste JA 12, 178
van der Loos M 129, 130, 136
van Durm M 315
van Lith M 24
van Vorhis RL 4, 206
Vaughn GR 333
Venus CA 333
Veress SA 49
Verhas M 401
Verschaeren A 401
Viola K 273
Voda JA 111
Vodovnik L 235
von Maltzahn WW 189
von Recum AF 47

Walker PS 38, 59
Wall DD 354
Wallston KA 266
Walsh N 6, 7, 8
Wampler II CW 143
Warren DH 295
Warren W 223
Waters R 164
Watson G 309
Wegener S 258
Weinrich M 334
Weinstein A 261
Weir D 208
Weiser S 271
Weisgerber RA 389
Weiss M 80
Weldon EJ Jr 302
Wells MS 66
Werner G 368
Wertsch JJ 302, 394
Wertz RT 392

Whalen R 65
 Whang J 11, 376, 377
 Wharton G 188, 191
 Whittaker S 309
 Whittle MW 40
 Wikswo J 237
 Willard MJ 110
 Williams BT 363
 Williams E 73
 Williams ME 362
 Wilson AB Jr 16, 186
 Wilson GL 384
 Winsten CJ 207
 Winter WG 32
 Wirta RW 9, 18, 205

Wise M 191
 Wixson RL 43, 44, 61
 Wolf PA 345
 Woo SL-Y 50, 240, 241, 254,
 255, 256
 Worthington-Roberts B 354
 Wright B 300
 Wurster RD 84, 171
 Wyss CR 234
 Wyss C 233

 Yabut S 273
 Yacoob PEY 10
 Yamaguchi G 199
 Yang RC 357

Yelin EH 262
 Yeo JD 176
 Yernault JC 371
 Young J 122
 Yund EW 313

 Zablocki CJ 302
 Zajac FE 173, 176, 199, 203,
 209, 216, 217, 218, 219
 Zhou B-H 167, 250
 Zilvoid G 12, 178
 Ziskind-Conhaim L 105
 Zomlefer MR 119, 147
 Zurek PM 319

HV1786

R266

1986

Copy 1

Rehabilitation

R&D progress

reports:1986

DATE DUE

HV1786

R266

1986

Copy 1

Rehabilitation R&D

progress

reports:1986

ISSUED TO

REFERENCE.

